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## STRESSES IN BEAMS.

By Prof. DeVOLSON WOOD.

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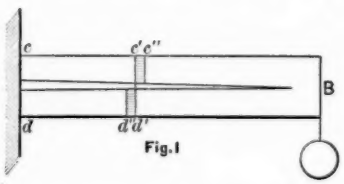
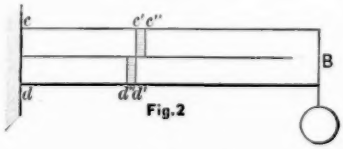
Mr. D. H. Clark, in his Manual of Rules, Tables and Data, makes a statement in regard to the "Theory of Flexure," which, in our opinion, ought not to go unnoticed. He is an authority of such high character that his statements on such problems are liable to be accepted without being questioned; and hence it is the more important that any error should be corrected. Assuming that many of our readers have not the work conveniently at hand, we make the following lengthy extract from pp. 504, 505, from the work above referred to, that the reader may the more conveniently get that author's argument and statement as presnted by himself:

"These, the normal stresses or resistances due to the absolute horizontal compression and extension of the beam are supplemented by diagonal resistances by which each of them is augmented 75 per cent.

"To elucidate the origin of diagonal resistance, it may be observed that the upper and lower portions of a beam—above and below the neutral axis—may be considered as two individual members of a frame united at their surface of contact—the neutral one. Let *cBd*, Fig. 1, be a triangular frame fixed at *ca* and loaded at B. The pieces *cc''* and *dd''* of the upper and lower members are respectively extended and compressed, when the load is applied to the length




*cc''* and *dd.''* If the members of the frame are placed parallel to each other in close contact, as in Fig 2, extension




and compression take place as before. Let now the two members be united in the line *nop*, Fig. 3, and so consolidated as to form a semi-beam; the extension and the compression partially neutralize each other: at the neutral line *nop*, they are absolutely neutralized and the amounts of extension and of compression are represented by the triangles *c' c'' o*

and $d'd''$ $o$. The structure is thus, in a certain sense, crippled, and the extension

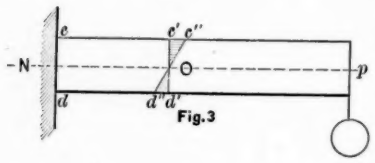


Fig.3

and compression, instead of being rectilineal, are curvilineal, and the semi-beam is deflected, as in Fig. 4. The counteraction here pointed out is necessarily ex-

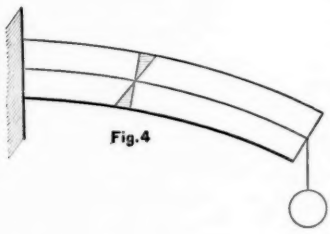


Fig.4

erted diagonally, at an angle of 45° with the neutral line; as in the line $c'o'$, Fig. 5, with the transverse section $c'd'$.

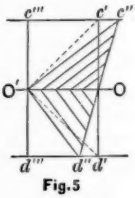


Fig.5

"In the intervention of the diagonal stress in deflected rectangular beams, according to the analysis in the text, is found the solution of the mystery of the 'resistance of flecture,' which has been so denominated, and has been experimentally demonstrated by Mr. W H. Barlow. The contrast between the action of the diagonal bracing of lattice girders, and that of the solid web of web girders, throws a flood of light on the recondite strains in webs and in solid beams."

The assertion that the "diagonal resistances' augments the absolute horizontal compressions and extensions 75 per cent., is entirely gratuitous. No argument is presented to support it. Every student of the flexure of beams knows wherein the difficulty lies. The computed value of the stress on the most remote elements of a beam at the instant of rupture. does not agree either with the tensile or compressive strength. If the tensile strength T of cast iron be 15,000 pounds, per square inch, and the crushing strength C be 100,000 pounds, it will be found that the modulus of rupture R for beams will be some intermediate value, say, about 35,000 pounds per square inch. To account for this discrepancy, Barlow proposed his "resistance of flexure" and made experiments upon beams of various forms, and with different materials, and many of the results of which seemed to substantiate his theory. But certain elements of his theory are in direct conflict with well-established principles of statics, and it is certainly unsafe to hold to any theory, however plausible it may appear by itself, which violates other known laws. We will indicate these points.

He *assumed* that the shearing stress was uniformly distributed over the cross-section; but for homogeneous materials, the theory shows that it is greatest at the neutral axis and zero at the upper and lower elements, as shown in the writer's *Resistance of Materials*, article 179, where also the specific law for rectangular beams is deduced. In the light of this fact it cannot be claimed that the shearing stress will be uniform over the cross-section.

Again, it is well known in statics that a longitudinal shear is accompanied by an equal transverse shear at any point; just as one couple necessitates an opposite couple of equivaient moment to produce equilibrium. In case, then, there is no transverse shear there will be no longitudinal shear. If a beam be supported at its ends and loaded with two equal weights equidistant from the supports, there will be no transverse shear between the loaded points, for the algebraic sum of the loads on the middle portion will be zero. But Barlow *assumed* that shear exists wherever there is bending, and hence, in this case, is in direct violation of established principles. We are not

aware that any experiments have been made under these conditions for the purpose of testing theory.

Again, he *assumed* that the ultimate "resistance of flexure" varied directly as the ultimate stress on the remote elements. According to his experiments, it nearly equals $t$ (the tenacity) for cast iron, and about $\frac{1}{2}t$ for wrought iron. Also that this resistance was due to the difference in the elongation of contiguous fibers. But these principles appear to be in conflict since the value of $t$ is absolute, and a deep beam will not be bent so much at the point of rupture as a more shallow one, and hence the relative elongations will be less in the former than in the latter case.

The remark of Mr. Clark, in the last sentence above quoted, does not remove the difficulty. Even admitting that the combined transverse shear and longitudinal pull produces an oblique stress, it does not follow that the latter will pass in a right line from the surface to the neutral axis, as illustrated in Fig. 5; and even if it did, we fail to find how it could reinforce the tensile resistance 75 per cent. Every computer of a truss bridge assumes that when the stress on the lower chord exceeds its tensile strength, the bridge will fail. He does not presume to add anything to the strength of the chords on account of the diagonal bracing. Again, admitting that the longitudinal pull and transverse shear produces a diagonal resultant, it follows that the direction of the resultant will be nearly parallel to the surface of the beam at the outer elements, since the transverse shear is very small in that vicinity, and the direct pull the greatest, and will be the diagonal of a square only on the neutral axis, where the only forces are equal rectangular shears.

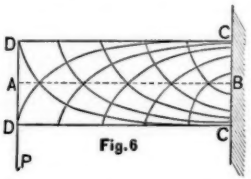


Fig. 6

The direction of the resultant stresses will be tangent to the lines in Fig. 6 at any point.

But a closer examination of Barlow's theory fails to indicate how the diagonal stresses are produced in accordance with it. Barlow seemed to consider that his "Resistance to Flexure" was caused by a *longitudinal* force, or shear, acting between contiguous elements unequally elongated, and if this view be correct, it is not easy to see how a diagonal resultant can be found, much less the grounds for the assertion that "the counteraction here pointed out is necessarily exerted diagonally at an angle of 45° with the neutral line."

But it still remains that the computed stress on the remote elements of a beam at rupture exceeds the tenacity of the material. The reason why the strength of a beam exceeds its computed strength when T, the modulus of tenacity, is used in place of the tabulated value of R in the formula for the strength of a beam, is due to the fact that the hypotheses upon which the analysis is founded are not realized in the experiment. The laws for elastic resistance are extended to that of ultimate strength, although it is well known that the laws fail when the elastic limit is passed. The outer fibers in the latter condition become relatively weakened, so that the effective depth—or more strictly, the depth which would represent the strength according to the assumed laws, is less than the measured depth of the beam. Thus, if T be the modulus of tenacity, its value for a rectangular beam supported at its ends, and broken by a load P at the middle, should be found by the formula

$$T=\frac{3\ P\ell}{2bd'^2}$$

in which, if a value for $d$ less than that of the measured depth be used, the resulting value will exceed T, as is actually found in practice. It is possible that this way of stating the case is original.

There is another reason for the discrepancy. It is assumed that the section of rupture is a plane—a condition never realized. The section of rupture being irregular, more elements must be separated than if it were plane, a condition which might give an apparent increase of strength.

It thus appears that the cause of the discrepancy between computed and observed values may be fully accounted for without involving hypotheses in conflict with other known principles.

## SCIENCE AND ENGINEERING.

From "Nature."

In the address delivered by Mr. Westmacott, President of the Institution of Mechanical Engineers, to the English and Belgian engineers assembled at Liége last August, there occurred the following passage: "Engineering brings all other sciences into play; chemical or physical discoveries, such as those of Faraday, would be of little practical use if engineers were not ready with mechanical appliances to carry them out and make them commercially successful in the way best suited to each."

We have no objection to make to these words, spoken at such a time, and before such an assembly. It would, of course, be easy to take the converse view, and observe that engineering would have made little progress in modern times but for the splendid resources which the discoveries of pure science have placed at her disposal, and which she has only had to adopt and utilize for her own purposes. But there is no need to quarrel over two opposite modes of stating the same fact. There *is* need, on the other hand, that the fact itself should be fairly recognized and accepted, namely, that science may be looked upon as at once the handmaid and the guide of art, art as at once the pupil and the supporter of science. In the present article we propose to give a few illustrations which will bring out and emphasise this truth.

We could scarcely find a better instance than is furnished to our hand in the sentence we have chosen for a text. No man ever worked with a more single-hearted devotion to pure science—with a more absolute disregard of money or fame, as compared with knowledge—than Michael Faraday. Yet future ages will perhaps judge that no stronger impulse was ever given to the progress of industrial art, or to the advancement of the material interests of mankind, than the impulse which sprang from his discoveries in electricity and magnetism. Of these discoveries we are only now beginning to reap the benefit. But we have merely to consider the position which the dynamo-electric machine already occupies in the industrial world, and the far higher position which, as almost all admit, it is destined to occupy in the future, in order to see how much we owe to Faraday's establishment of the connection between magnetism and electricity. That is one side of the question—the debt which art owes to science. But let us look at the other side also. Does science owe nothing to art? Will any one say that we should know as much as we do concerning the theory of the dynamo-electric motor, and the laws of electro-magnetic action generally, if that motor had never risen (or fallen, as you choose to put it) to be something besides the instrument of a laboratory or the toy of a lecture-room. Only a short time since the illustrious French physicist, M. Tresca, was enumerating the various sources of loss in the transmission of power by electricity along a fixed wire, as elucidated in the careful and elaborate experiments inaugurated by M. Marcel Deprez, and subsequently continued by himself. These losses—the electrical no less than the mechanical losses—are being thoroughly and minutely examined in the hope of reducing them to the lowest limit; and this examination cannot fail to throw much light on the exact distribution of the energy imparted to a dynamo machine, and the laws by which this distribution is governed. But would this examination ever have taken place—would the costly experiments which render it feasible ever have been performed—if the dynamo machine was still under the undisputed control of pure science, and had not become subject to the sway of the capitalist and the engineer?

Of course the electric telegraph affords an earlier and perhaps as good an illustration of the same fact. The discovery that electricity would pass along a wire and actuate a needle at the other end was at first a purely scientific one, and it was only gradually that its importance, from an industrial point of view, came to be recognized. Here, again, art

owes to pure science the creation of a complete and important branch of engineering, whose works are spread like a net over the whole face of the globe. On the other hand, our knowledge of electricity, and specially of the electrochemical processes which go on in the working of batteries, has been enormously improved in consequence of the use of such batteries for the purposes of telegraphy.

Let us turn to another example in a different branch of science. Whichever of our modern discoveries we may consider to be the most startling and important, there can, I think, be no doubt that the most beautiful is that of the spectroscope. It has enabled us to do that which, but a few years before its introduction, was taken for the very type of the impossible, viz., to study the chemical composition of the stars; and it is giving us clearer and clearer insight every day into the condition of the great luminary which forms the center of our system. Still, however beautiful and interesting such results may be, it might well be thought that they could never have any practical application, and that the spectroscope, at least, would remain an instrument of science, but of science alone. This, however, is not the case. Some thirty years since Mr. Bessemer conceived the idea that the injurious constituents of raw iron, such as silicon, sulphur, &c., might be got rid of by simple oxydation. The mass of crude metal was heated to a very high temperature; atmospheric air was forced through it at considerable pressure, and the oxygen, uniting with these metalloids, carried them off in the form of acid gases. The very act of union generated a vast quantity of heat, which itself assisted the continuance of the process; and the gas, therefore, passed off in a highly luminous condition. But the important point was to know where to stop; to seize the exact moment when all, or practically all, hurtful ingredients had been removed, and before the oxygen had turned from them to attack the iron itself. How was this point to be ascertained? It was soon suggested that each of these gases in its incandescent state would show its own peculiar spectrum; and that if the flame rushing out of the throat of the converter were viewed through a spectroscope, the moment when any substance, such as sulphur, had disappeared would be known by the disappearance of the corresponding lines in the spectrum. The anticipation, it is needless to say, was verified; and the spectroscope, though now superseded, had for a time its place among the regular appliances necessary for the carrying on of the Bessemer process.

This process itself, with all the momentous consequences, mechanical, commercial and economical, which it has entailed, might be brought forward as a witness on our side; for it was almost completetely worked out in the laboratory before being submitted to actual practice. In this respect it stands in marked contrast to the earlier processes for the making of iron and steel, which were developed, it is difficult to say how, in the forge or furnace itself, and amid the smoke and din of practical work. At the same time the experiments of Bessemer were for the most part carried out with a distinct eye to their future application in practice, and the value for our present purpose is therefore not so great. The same, we believe, may be said with regard to the great rival of the Bessemer converter, viz., the Siemens open hearth; although this forms in itself a beautiful application of the scientific doctrine that steel stands midway as regards its proportion of carbon, between wrought iron and pig iron, and ought, therefore to be obtainable by a judicious mixture of the two. The basic process is the latest development, in this direction, of science as applied to metallurgy. Here, by simply giving a different chemical constitution to the clay lining of the converter, it is found possible to eliminate phosphorus—an element which has successfully withstood the attack of the Bessemer system. Now, to quote the words of a German eulogizer of the new method, phosphorus has been turned from an enemy into a friend, and the richer a given ore is in that substance, the more readily and cheaply does it seem likely to be converted into steel.

These latter examples have been taken from the art of metallurgy; and it may of course be said that, considering the intimate relation between that art and the science of chemistry, there can be no wonder if the former is largely depend-

ent for its progress upon the latter. I will therefore turn to what may appear the most concrete, practical and unscientific of all arts—that, namely, of the mechanical engineer; and we shall find that even here examples will not fail us of the boons which pure science has conferred upon the art of construction, nor even, perhaps, of the reciprocal advantages which she has derived from the connection.

The address of Mr. Westmacott, from which I have already taken my text, supplies in itself more than one instance of the kind we seek—instances emphasized by papers read at the meeting where the address was spoken. Let us take, first, the manufacture of sugar from beet-root. This manufacture was forced into prominence in the early years of this century, when the continental blockade maintained by England against Napoleon prevented all importation of sugar from America; and it has now attained very large dimensions, as all frequenters of the Continent must be aware. The process, as exhaustively described by a Belgian engineer, M. Mélin, offers several instances of the application of chemical and physical science to practical purposes. Thus, the first operation in making sugar from beet-root is to separate the juice from the flesh, the former being as much as 95 per cent. of the whole weight. Formerly this was accomplished by rasping the roots into a pulp, and then pressing the pulp in powerful hydraulic presses; in other words, by purely mechanical means. This process is now to a large extent superseded by what is called the diffusion process, depending on the well-known physical phenomena of *endosmosis* and *exosmosis*. The beet-root is cut up into small slices, called "cossettes," and these are placed in vessels filled with water. The result is, that a current of endosmosis takes place from the water towards the juice in the cells, and a current of exosmosis from the juice towards the water. These currents go on cell by cell, and continue until a state of equilibrium is attained. The richer the water and the poorer the juice, the sooner does this equilibrium take place. Consequently the vessels are arranged in a series, forming what is called a diffusion battery; the pure water is admitted to the first vessel, in which the slices have already been nearly exhausted, and subtracts from them what juice there is left. It then passes as a thin juice to the next vessel, in which the slices are richer, and the process begins again. In the last vessel the water which has already done its work in all the previous vessels, comes into contact with fresh slices, and begins the operation upon them. The same process has been applied at the other end of the manufacture of sugar. After the juice has been purified, and all the crystallizable sugar has been separated from it by boiling, there is left a mass of molasses containing so much of the salts of potassium and sodium that no further crystallization of the yet remaining sugar is possible. The object of the process called osmosis is to carry off those salts. The apparatus used, or osmogene, consists of a series of trays filled alternately with molasses and water, the bottoms being formed of parchment paper. A current passes through this paper in each direction, part of the water entering the molasses, and part of the salts, together with a certain quantity of sugar, entering the water. The result of thus freeing the molasses from the salts is that a large part of the remaining sugar can now be extracted by crystallization.

Another instance in point comes from a paper dealing with the question of the construction of long tunnels. In England this has been chiefly discussed of late in connection with the Channel Tunnel, where, however, the conditions are comparatively simple. It is of still greater importance abroad. Two tunnels have already been pierced through the Alps; a third is nearly completed, and a fourth, the Simplon Tunnel, which will be the longest of any, is at this moment the subject of a most active study on the part of French engineers. In America, especially in connection with the deep mines of the Western States, the problem is also of the highest importance. But the driving of such tunnels would be financially if not physically impossible, but for the resources which science has placed in our hands, first, by the preparation of new explosives, and, secondly, by methods of dealing with the very high temperatures which have to be encountered. As regards the first, the history of explosives is scarcely anything else

than a record of the application of chemical principles to practical purposes—a record which, in great part has yet to be written, and on which we cannot here dwell. It is certain, however, that but for the invention of nitroglycerine, a purely chemical compound, and its development in various forms, more or less safe and convenient, these long tunnels would never have been constructed. As regards the second point, the question of temperature is really the most formidable with which the tunnel engineer has to contend. In the St. Gothard Tunnel, just before the meeting of the two headings, in February, 1880, the temperature rose as high as 93° Fahr. This, combined with the foulness of the air, produced an immense diminution in the work done per person and per horse employed whilst several men were actually killed by the dynamite gases, and others suffered from a disease which was traced to a hitherto unknown species of internal worm. If the Simplon Tunnel should be constructed yet higher temperatures may probably have to be dealt with. Although science can hardly be said to have completely mastered these difficulties, much has been done in that direction. A great deal of mechanical work has, of course, to be carried on at the face or far end of such a heading, and there are various means by which it might be done. But by far the most satisfactory solution, in most cases at least, is obtained by taking advantage of the properties of compressed air. Air can be compressed at the end of the tunnel either by steam-engines, or, still better, by turbines where water power is available. This compressed air may easily be led in pipes to the face of the heading, and used there to drive the small engines which work the rock-drilling machines, &c. The efficiency of such machines is doubtless low, chiefly owing to the physical fact that the air is heated by compression, and that much of this heat is lost whilst it traverses the long line of pipes leading to the scene of action. But here we have a great advantage from the point of view of ventilation; for, as the air gained heat while being compressed, so it loses heat while expanding; and the result is that a current of cold and fresh air is continually issuing from the machines at the face of the heading, just where it is most wanted. In consequence, in the St. Gothard, as just alluded to, the hottest parts were always some little distance behind the face of the heading. Although in this case as much as 120,000 cubic meters of air (taken at atmospheric pressure) were daily poured into the heading, yet the ventilation was very insufficient. Moreover, the high pressure which is used for working the machines is not the best adapted for ventilation; and in the Arlberg tunnel separate ventilating pipes are employed, containing air compressed to about one atmosphere, which is delivered in much larger quantities, although not at so low a temperature. In connection with this question of ventilation a long series of observations have been taken at the St. Gothard, both during and since the construction; these have revealed the important physical fact (itself of high practical importance) that the barometer never stands at the same level on the two sides of a great mountain chain; and so have made valuable contributions to the science of meteorology.

Another most important use of the same scientific fact, namely, the properties of compressed air, is found in the sinking of foundations below water. When the piers of a bridge, or other structure, had to be placed in a deep stream, the old method was to drive a double row of piles round the place and fill them in with clay, forming what is called a cofferdam. The water was pumped out from the interior, and the foundation laid in the open. This is always a very expensive process, and in rapid streams is scarcely practicable. In recent times large bottomless cases, called caissons, have been used, with tubes attached to the roof, by which air can be forced into or out of the interior. These caissons are brought to the site of the proposed pier, and are there sunk. Where the bottom is loose, sandy earth, the Vacuum process, as it is termed, is often employed; that is, the air is pumped out from the interior, and the superincumbent pressure then causes the caisson to sink and the earth to rise within it. But it is more usual to employ what is called the Plenum process, in which air under high pressure is pumped into the caisson and expels the water, as in a diving bell. Workmen

then descend, entering through an air lock, and excavate the ground at the bottom of the caisson, which sinks gradually as the excavation continues. Under this system a length of some two miles of quay wall is being constructed at Antwerp, far out in the channel of the river Scheldt. Here the caissons are laid end to end with each other, along the whole curve of the wall, and the masonry is built on the top of them within a floating cofferdam of very ingenious construction.

There are few mechanical principles more widely known than that of so-called centrifugal force; an action which, though still a puzzle to students, has long been thoroughly understood. It is, however, comparatively recently that it has been applied in practice. One of the earliest examples was, perhaps, the ordinary governor, due to the genius of Watt. Every boy knows that if he takes a weight hanging from a string and twirls it round, the weight will rise higher and revolve in a larger circle as he increases the speed. Watt saw that if he attached such an apparatus to his steam engine, the balls or weights would tend to rise higher whenever the engine began to run faster, that this action might be made partly to draw over the valve which admitted the steam, and that in this way the supply of steam would be lessened, and the speed would fall. Few ideas in science have received so wide and so successful an application as this; but of late years another property of centrifugal force has been brought into play. The effect of this so-called force is that any body revolving in a circle has a continual tendency to fly off at a tangent; the amount of this tendency depending jointly on the mass of the body and on the velocity of the rotation. It is the former of these conditions which is now being taken advantage of. For if we have a number of particles all revolving with the same velocity, but of different specific gravities, and if we allow them to follow their tendency of moving off at a tangent, it is evident that the heaviest particles having the greatest mass will move with the greatest energy. The result is, that if we take a mass of such particles and confine them within a circular casing, we shall find that, having rotated this casing with a high velocity and for a sufficient time, the heaviest particles will have settled at the outside and the lightest at the inside, whilst between the two there will be a gradation from the one to the other. Here, then, we have the means of separating two substances, solid or liquid, which are intimately mixed up together, but which are of different specific gravities. This physical principle has been taken advantage of in a somewhat homely but very important process, viz., the separation of cream from milk. In this arrangement the milk is charged into a vessel something of the shape and size of a Gloucester cheese, which stands on a vertical spindle, and is made to rotate with a velocity as high as 7,000 revolutions per minute. At this enormous speed the milk, which is the heavier, flies to the outside, while the cream remains behind and stands up as a thin layer on the inside of the rotating cylinder of fluid. So completely does this immense speed produce in the liquid the characteristics of a solid, that if the rotating shell of cream be touched by a knife it emits a harsh, grating sound, and gives the sensation experienced in attempting to cut a stone. The separation is almost immediately complete, but the difficult point was to draw off the two liquids separately and continuously without stopping the machine. This has been simply accomplished by taking advantage of another principle of hydromechanics. A small pipe opening just inside the shell of the cylinder is brought back to near the center, where it rises through a sort of neck and opens into an exterior casing. The pressure due to the velocity causes the skim-milk to rise in this pipe and flow continuously out at the inner end. The cream is at the same time drawn off by a similar orifice made in the same neck and leading into a different chamber.

Centrifugal action is not the only way in which particles of different specific gravity can be separated from each other by motion only. If a rapid "jigging" or up-and-down motion be given to a mixture of such particles, the tendency of the lighter to fly further under the action of the impulse causes them gradually to rise to the upper surface; this surface being free in the present case, and the result being therefore the reverse of what happens in the rotating

chamber. If such a mixture be examined after this up-and-down motion has gone on for a considerable period, it will be found that the particles are arranged pretty accurately in layers, the lightest being at the top and the heaviest at the bottom. This principle has long been taken advantage of in such cases as the separation of lead ores from the matrix in which they are embedded. The rock, in these cases, is crushed into small fragments, and placed on a frame having a rapid up and-down motion, when the heavy lead ore gradually collects at the bottom and the lighter stone on the top. To separate the two the machine must be stopped and cleared by hand. In the case of coal-washing, where the object is to separate fine coal from the particles of stone mixed with it, this process would be very costly, and indeed impossible, because a current of water is sweeping through the whole mass. In the case of the Coppée coal-washer, the desired end is achieved in a different and very simple manner. The well-known mineral feldspar has a scientific gravity intermediate between that of the coal and the shale, or stone, with which it is found intermixed. If, then, a quantity of feldspar in small fragments is thrown into the mixture, and the whole then submited to the jigging process, the result will be that the stone will collect on the top and the coal at the bottom, with a layer of feldspar separating the two. A current of water sweeps through the whole, and is drawn off partly at the top, carrying with it the stone, and partly at the bottom, carrying with it the fine coal.

The above are instances where science has come to the aid of engineering. Here is one in which the obligation is reversed. The rapid stopping of railway trains, when necessary, by means of brakes, is a problem which has long occupied the attention of many engineers; and the mechanical solutions offered have been correspondingly numerous. Some of these depend on the action of steam, some of a vacuum, some of compressed air, some of pressure water; others again ingeniously utilize the momentum of the wheels themselves. But for a long time no effort was made by any of these inventors thoroughly to master the theoretical conditions of the problem before them. At last, one of the most ingenious and successful among them, Mr. George Westinghouse, resolved to make experiments on the subject, and was fortunate enough to associate with himself Captain Douglas Galton. Their experiments, carried on with rare energy and perseverance, and at great expense, not only brought into the clearest light the physical conditions of the question (conditions which were shown to be in strict accordance with theory), but also disclosed the interesting scientific fact that the friction between solid bodies at high velocities is not constant, as the experiments of Morin had been supposed to imply, but diminishes rapidly as the speed increases —a fact which other observations serve to confirm.

The old scientific principle known as the hydrostatic paradox, according to which a pressure applied at any point of an inclosed mass of liquid is transmitted unaltered to every other point, has been singularly fruitful in practical applications. Mr. Bramah was perhaps the first to recognize its value and importance. He applied it to the well-known Bramah press, and in various other directions, some of which were less successful. One of these was a hydraulic lift, which Mr. Bramah proposed to construct by means of several cylinders sliding within each other after the manner of the tubes of a telescope. His specification of this invention sufficiently expresses his opinion of its value, for it concludes as follows: "This patent does not only differ in its nature and in its boundless extent of claims to novelty, but also in its claims to merit and superior utility compared with any other patent ever brought before or sanctioned by the legislative authority of any nation." The telescope lift has not come into practical use; but lifts worked on the hydraulic principle are becoming more and more common every day. The same principle has been applied by the genius of Sir William Armstrong, and others, to the working of cranes and other machines for the lifting of weights, &c.; and, under the form of the accumulator, with its distributing pipes and hydraulic engines, it provides a store of power always ready for application at any required point in a large system, yet costing practically nothing when not actu-

ally at work. This system of high-pressure mains worked from a central accumulator has been for some years in existence at Hull, as a means of supplying power commercially for all the purposes needed in a large town, and it is at this moment being carried out on a wider scale in the East End of London.

Taking advantage of this system, and combining with it another scientific principle of wide applicability, Mr. J. H. Greathead has brought out an instrument called the "injector hydrant," which seems likely to play an important part in the extinguishing of fires. This second principle is that of the lateral induction of fluids, and may be thus expressed in the words of the late William Froude: "Any surface which, in passing through a fluid, experiences resistance, must, in so doing, impress on the particles which resist it a force in the line of motion equal to the resistance." If, then, these particles are themselves part of a fluid, it will result that they will follow the direction of the moving fluid and be partly carried along with it. As applied in the injector hydrant, a small quantity of water derived from the high-pressure mains is made to pass from one pipe into another, coming in contact at the same time with a reservoir of water at ordinary pressure. The result is, that the water from the reservoir is drawn into the second pipe through a trumpet-shaped nozzle, and may be made to issue as a stream to a considerable height. Thus, the small quantity of pressure-water, which, if used by itself, would perhaps rise to a height of 500 feet, is made to carry with it a much larger quantity to a much smaller height, say that of an ordinary house.

The above are only a few of the many instances which might be given to prove the general truth of the fact with which we started, namely, the close and reciprocal connection between physical science and mechanical engineering, taking both in their widest sense. It may possibly be worth while to return again to the subject, as other illustrations arise. Two such have appeared, even at the moment of writing, and though their practical success is not yet assured, it may be worth while to cite them. The first is an application of the old principle of the siphon to the purifying of sewage. Into a tank containing the sewage dip a siphon pipe some thirty feet high, of which the shorter leg is many times larger than the longer. When this is started, the water rises slowly and steadily in the shorter column, and before it reaches the top has left behind it all, or almost all, of the solid particles which it previously held in suspension. These fall slowly back through the column, and collect at the bottom of the tank, to be cleared out when needful. The effluent water is not, of course, chemically pure, but sufficiently so to be turned into any ordinary stream. The second invention rests on a curious fact in chemistry, namely, that caustic soda or potash will absorb steam, forming a compound which has a much higher temperature than the steam absorbed. If, therefore, exhaust steam be discharged into the bottom of a vessel containing caustic alkali, not only will it become condensed, but this condensation will raise the temperature of the mass so high that it may be employed in the generation of fresh steam. It is needless to observe how important will be the bearing of this invention upon the working of steam engines for many purposes, if only it can be established as a practical success. And if it is so established, there can be no doubt that the experience thus acquired will reveal new and valuable facts with regard to the conditions of chemical combination and absorption, in the elements thus brought together.

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An experiment on the loss of pressure of steam in a long steam pipe was lately made in the Gould and Curry mine, California, by Mr. R. G. Carlyle, engineer. The pipes used were four-inch gas pipes connected with flanges and placed in a long trough made of twelve-inch by two-inch planks, and thus eight inches square inside. The space between pipe and wood was filled up with wood. Although the pipe was one thousand three hundred and forty-one feet in length there was practically no difference between the pressure at the boiler and at the engine, and this was proved by several gauges and mercury columns. Mr. Carlyle concludes that there is no limit to the distance to which steam may be carried.

# PRESSURE ATTAINABLE BY THE USE OF THE "DROP PRESS."

By ROBERT H. THURSTON, HOBOKEN, N. J.

The writer has recently taken occasion to determine the magnitude of the pressures attainable and not infrequently utilized in the use of the "drop press," now so extensively employed in the process of "drop forging," and in the manufacture of small parts of sewing machines, firearms and light machinery.

The opportunity was offered to make this determination in the course of an investigation of the efficiency of drop presses lately made by the Mechanical Laboratory of the Stevens Institute of Technology. It was found that the most efficient presses experimented with had an "efficiency," as the term is technically used, of 90 per cent.—*i. e.*, the work done by the drop was 90 per cent. of that which was due to the weight falling through the measured height. The table given below is based upon the assumption that this efficiency can be reached, and exhibits the mean pressure attained when the piece attacked is crushed to the amount of $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$ inch respectively. The maximum pressures must exceed those given. The mean pressures are calculated by determining the amount of energy of the falling drop at the instant before stopping—*i. e.*, of the quantity of work done upon it by gravity and stored in it, and dividing that measure in foot-pounds by the distance through which the crushing of the "work" takes place. These figures are seen to be simply enormous, and the power of this form of press is evidently limited only by the rigidity of its parts and their strength.

The figures given for the pressures reached when the compression is $\frac{1}{16}$ inch can only be obtained when the anvil is so set and of such material that the yielding there occurring cannot absorb more than the allowed 10 per cent. of the total work of the falling mass. The same remark applies to the table generally, but the loss may always be expected to fall within the assumed figure for the smaller weights and lesser heights fallen through. If the machine is well built and the anvil and foundation are of ample size and rigidity for good work, it is not improbable that the higher figures can be readily obtained; also, if proper precautions are taken in the setting of the press.

The *intensity* of pressure attainable is evidently determined by the area of the surface exposed to the action of the drop, and this in turn determines the distance through which crushing may occur. The figures given in the table are total pressures, and the mean intensity of pressure corresponding to these amounts is to be obtained by dividing the total pressure as shown in the table by the area of section of the crushed piece, or by the mean area opposed to the crushing action during the operation. The proper comparison is that of the energy of the falling weight with the "resilience," elastic or total, or both, of the mass on the anvil or in the dies.

The limit to the resistance of any mass on the anvil is found at the pressure at which the metal will "flow" continuously. This pressure varies with not only the kind of metal, but with every variation in the chemical composition, the physical structure or the form and method of support of the piece. For general use the value of this "modulus" may be taken at about the value of the shearing resistance of the material. For soft wrought iron, for example, it may be taken at about 50,000 pounds per square inch (3,515 kg. per sq. cm.) for moderately hard iron at a figure 20 per cent. higher, and for pure copper at about one-half the latter figure. There is, however, a great difference in the behavior of the two metals under pressure. The former has a distinct elastic limit in its original state, which becomes "exalted," as was shown by the writer some ten years ago, when the piece is distorted, and becomes approximately equal to the maximum force, producing change of form, remaining permanently altered. The metal thus transformed does not yield subse-

PRESSURES OF THE DROP PRESS.—(EFFICIENCY 90 PER CENT.)

| Fall of drop in feet and inches. | Compression in inches. | Weights of Drop. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pounds. 50. | Pounds. 100. | Pounds. 200. | Pounds. 400. | Pounds. 600. | Pounds. 800. | Pounds. 1,000. | Pounds. 1,500. | Pounds. 2,000. |
| Ft.Ins. | Ins. | | | | | | | | | |
| 0 3 | 1/16 | 2,160 | 4,320 | 8,640 | 17,281 | 25,921 | 34,562 | 43,202 | 64,803 | 86,405 |
| | 1/8 | 1,080 | 2,160 | 4,320 | 8,640 | 12,960 | 17,281 | 21,601 | 32,401 | 43,202 |
| | 1/4 | 540 | 1,080 | 2,160 | 4,320 | 6,480 | 8,640 | 10,800 | 16,200 | 21,601 |
| 0 6 | 1/16 | 4,320 | 8,640 | 17,281 | 34,562 | 51,843 | 69,124 | 86,405 | 129,607 | 172,811 |
| | 1/8 | 2,160 | 4,320 | 8,640 | 17,281 | 25,921 | 34,562 | 43,202 | 64,803 | 86,405 |
| | 1/4 | 1,080 | 2,160 | 4,320 | 8,640 | 12,960 | 17,281 | 21,601 | 32,402 | 43,202 |
| 0 9 | 1/16 | 6,480 | 12,960 | 25,921 | 51,843 | 77,764 | 103,686 | 129,608 | 194,412 | 259,216 |
| | 1/8 | 3,240 | 6,480 | 12,960 | 25,921 | 38,882 | 51,843 | 64,804 | 87,206 | 129,608 |
| | 1/4 | 1,620 | 3,240 | 6,480 | 12,960 | 19,441 | 25,921 | 32,402 | 43,603 | 64,804 |
| 1 0 | 1/16 | 8,640 | 17,281 | 34,562 | 69,124 | 103,687 | 138,249 | 172,811 | 259,216 | 345,622 |
| | 1/8 | 4,320 | 8,640 | 17,281 | 34,562 | 51,843 | 69,124 | 86,405 | 129,608 | 172,811 |
| | 1/4 | 2,160 | 4,320 | 8,640 | 17,281 | 25,922 | 34,562 | 43,202 | 64,804 | 86,405 |
| 1 6 | 1/16 | 12,960 | 25,921 | 51,843 | 103,686 | 155,529 | 207,373 | 259,216 | 388,824 | 518,432 |
| | 1/8 | 6,480 | 12,960 | 25,921 | 51,843 | 77,764 | 103,686 | 139,608 | 194,412 | 259,216 |
| | 1/4 | 3,240 | 6,480 | 12,960 | 25,921 | 38,882 | 51,843 | 64,804 | 87,206 | 129,608 |
| 2 0 | 1/16 | 17,281 | 34,562 | 69,124 | 138,249 | 207,373 | 276,498 | 345,622 | 518,433 | 691,244 |
| | 1/8 | 8,640 | 17,281 | 34,562 | 69,124 | 103,686 | 138,249 | 172,811 | 259,216 | 345,622 |
| | 1/4 | 4,320 | 8,640 | 17,281 | 34,562 | 51,843 | 69,124 | 86,405 | 129,608 | 172,811 |
| 2 6 | 1/16 | 21,601 | 43,202 | 86,405 | 172,811 | 259,216 | 345,622 | 432,028 | 648,042 | 864,056 |
| | 1/8 | 10,800 | 21,601 | 43,202 | 86,405 | 129,608 | 172,811 | 216,014 | 324,021 | 432,028 |
| | 1/4 | 5,400 | 10,800 | 21,601 | 43,202 | 64,804 | 86,405 | 180,007 | 162,010 | 216,014 |
| 3 0 | 1/16 | ..... | 51,843 | 103,686 | 207,373 | 311,059 | 414,747 | 518,433 | 777,649 | 1,036,866 |
| | 1/8 | ..... | 25,921 | 51,843 | 103,686 | 155,529 | 207,373 | 259,216 | 388,824 | 518,433 |
| | 1/4 | ..... | 12,960 | 25,921 | 51,843 | 77,764 | 103,686 | 129,608 | 194,412 | 259,216 |
| 3 6 | 1/16 | ..... | ..... | 120,967 | 241,935 | 362,902 | 483,871 | 604,838 | 916,257 | 1,209,677 |
| | 1/8 | ..... | ..... | 60,483 | 120,967 | 181,951 | 241,935 | 302,419 | 458,128 | 604,838 |
| | 1/4 | ..... | ..... | 30,241 | 60,483 | 90,975 | 120,967 | 151,209 | 229,064 | 302,419 |
| 4 0 | 1/16 | ..... | ..... | ..... | 276,498 | 414,747 | 552,996 | 691,244 | 1,036,866 | 1,382,488 |
| | 1/8 | ..... | ..... | ..... | 138,249 | 207,373 | 276,498 | 345,622 | 518,433 | 691,244 |
| | 1/4 | ..... | ..... | ..... | 69,124 | 103,686 | 138,249 | 172,811 | 259,216 | 345,622 |
| 5 0 | 1/16 | ..... | ..... | ..... | ..... | 518,434 | 691,245 | 864,056 | 1,296 084 | 1,728,112 |
| | 1/8 | ..... | ..... | ..... | ..... | 259,217 | 345,622 | 432,028 | 648,042 | 864,056 |
| | 1/4 | ..... | ..... | ..... | ..... | 129,609 | 172,811 | 216,014 | 324,021 | 432,028 |

quently to any less pressure. It will not flow under any pressure less than that which is required to produce distortion immediately upon its application. Copper, however, has no true and measurable elastic limit in its original condition as found in the market, and it does flow under the continued action of forces far less than those required to produce rapid and continuous distortion by steady pressure. A load which produces no visible effect when first applied will after a time be found to have caused a very decided, and often a very extensive, alteration of the form of the mass. This is also a now well-known property of some kinds of brass and of many other metals belonging to what the writer has called the tin class, to distinguish them from the metals of the iron and steel class, which do not exhibit this treacherous behavior. This difference is of some

importance, not only as indicating the best method of working them, but also as showing that the first of these two classes is a safer class to deal with where the metal is to be used in the carrying of heavy and unintermitted stress than is the second class.

Another important distinction between these two classes is, as indicated by the results of investigations made by the writer, that the "iron class," which includes all the irons and all of the steels, offers more resistance as the rupturing action is slower, while the "tin class," which includes nearly all the other metals, and very nearly all of the alloys that the writer has ever tested, yields the more readily the more slowly the distortion goes on. The second class is thus subject to that singular kind of change of form under heavy, continuous stress which is illustrated in the movement of all viscous solids—ice, for example, as seen in its flow in the glacier. This, it seems probable, may often occur under pressures far within those which are required to cause change of form in the testing machine in the ordinary methods of test. Iron has been found by Vicat, and later by the writer, to exhibit something of such a phenomenon, but only when the pressures are considerably above one-half those usually found for the moduli of rupture, and this action is only seen in serious degree when the iron has been annealed and thus softened. Common merchant iron, so far as the writer is aware, does not show any tendency to such slow and imperceptible yielding under moderate loads.

The bearing of these facts upon the value of the drop press as a means of working iron and other metals into shape is obvious. Change of form can only begin when the elastic limit of the material is passed, and flow can only progress steadily and uninterruptedly when the pressure applied is in excess of the resistance of the metal to flow. The soft metals which belong to the "tin class" are best attacked by processes which cause a comparatively slow motion of their particles in changing form; iron and steel, on the contrary, being less resistant at high than at low velocities of flow, are best worked by methods which produce rapid distortion. Professor Kick, of Prague, has shown very plainly that this difference in the amount of work demanded by the soft metals under the two kinds of treatment may amount to a very important quantity. He finds that the distortion of bodies by the action of the hydraulic press and by the action of a hammer dealing a succession of blows to produce the same change of form consume power in the ratio, in some cases, of one to ten. It is thus evident that the hammer or the drop is to be used for those special cases in which the pressure desired cannot be reached by ordinary methods, and that it is best adapted to the working of iron and steel. The hydraulic press and automatic machinery are to be preferred where they can be conveniently and cheaply used. For much of the work that is now done in our smaller kinds of manufacturing, the drop has been shown by experience to be the only machine which will give the required enormous pressures and do the work rapidly and cheaply.

The maximum area of surface exposed to pressure which will be allowable for any given amount of compression can be determined approximately by dividing the total mean pressure due to the action of the drop, with the given fall, and the proposed compression by the maximum resistance of the material. The maximum area which will permit any action upon the surface is to be ascertained by dividing the same maximum pressure due the fall of the drop by the elastic limit of the metal in compression.

The total work absorbed, or the resilience of the mass, up to the elastic limit is to be measured by multiplying the elastic resistance by one-half the percentage of compression which marks the elastic limit; the result measures the resilience in inch-pounds when the unit of measure is the inch, and in centimeter-kilograms when the units are metric. The total work done in any permanent change of shape is proportional to the volume affected and to the maximum resistance of the material to such deformation.

What figures shall be adopted for the resistance to be calculated upon in the production of flow in metals subjected to the action of the drop press is a question which the writer is unable to answer definitely. It would seem probable that

the effect of the blow may be, in the case of cold metal, somewhat similar to that of cold rolling, and, this being the case, the initial resistance to flow must be taken as at least 70,000 pounds per square inch 4,921 kg. per sq. cm.), and the resilience during flow at as high as 70,000 inch-pounds per cubic inch (4,921 kg. m. per cubic centimeter) for good common wrought iron. It may be safe to take the figure for hot iron, as usually worked, at less than one-half this amount. For copper the writer would, in the absence of exact data, take the work of deformation to be two-thirds that of iron for pieces of small section, and would expect a great increase of resistance with either metal when the surface acted upon by the drop becomes large in proportion to its thickness. Probably no very reliable figures can yet be given. Whatever the resistance may be, the drop will be very certain to overcome it, and the variation in its amount will simply determine how many blows must be struck to obtain a given amount of change of form.

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## HYDRAULIC ARCHITECTURE.

From "The Builder."

No portion of the duty of either the architect or the engineer is so difficult as that which relates to hydraulic constructions. There are many reasons for this, such as the great cost and trouble of obtaining foundations below water, the different behavior of various kinds of cement, and of other materials, in the air and in the water, the variation in the stability due to weight, from the buoyant action of the water, and other causes. But probably the chief difficulty lies in the absence of satisfactory theory. For all kinds of terrestrial structures, from the simplest form of cottage to the loftiest vault, burdened with impossible pendants, or soaring between flying buttresses and pinnacles, the definite mathematical law can be detected and expressed. It is true that the draughtsman rather leans on practice and experience than on geometric or algebraic analysis. But if the latter be wanted, in the case of any new and unprecedented construction, it is attainable; and within the last few years, as those columns of our own which are devoted to reviews bear ample witness, so much thought has been given to the subject of the graphic solution of structural problems that there is hardly a question which can be put to the architect of which he cannot work out the answer on the drawing board.

The case is far otherwise when water has to be taken into account. Instances of the disastrous failure of costly works for hydraulic purposes are not so rare as might be desired. Thus in May, 1847, the Government of India directed that the works on the Ganges Canal, designed by Sir Proby Cautley, should be vigorously carried out. Water was admitted into the canal in April, 1854, but during the next few years defects in the work came gradually to light, the chief of which was the "excessive declivity in the bed of the main channel, which caused a velocity of current greater than the sandy soil was calculated to withstand without erosion" (Buckley's "Irrigation Works of India," p. 101); yet the gradient was only 18 inches per mile. In 1863 Sir Arthur Cotton estimated the alterations and additions to this canal at £2,725,000; and proposed to reduce the inclination of the bed of the canal by from 3 inches to 6 inches per mile. But there is no doubt that Sir Proby Cautley had followed the formula of Dubuat, which at the time was, and indeed still is, an accepted authority for the setting-out of canals.

But we need not go to India for an illustration of the imperfect acquaintance with hydraulic law which is as yet characteristic of the state of science. As recently as 1864 the Mersey Board so far completed the works of the Low Water Basin at Birkenhead that water was run for the first time through the sluicing conduits. "But from some cause," says Mr. Ellacott, in his description of the

basin (Min. Proc. Inst. C. E., vol. xxviii., p. 525), "which was never clearly accounted for, such a violent shock was communicated to a portion of the masonry forming the back of the landing-stage recess, that the wall was instantly forced over 5 inches out of the perpendicular. Except for the purpose of sluicing under the landing-stage, no further attempt was made to run the water through the culvert. No trial was ever attempted of the corresponding culvert on the north side of the basin." Again, "on January 25, during the fourth trial of the sluices, the gates of the north channel were torn from their fastenings, and swept into the chamber. On the 21st of July the gates of the south sluicing chamber were carried away in a similar manner." After the 15th of November, 1864, when the last trial of the sluice was made, it was found that the sheet piling in front of the apron was bare on the face to a depth of 4 feet, that a hole 9 feet deep below the finished bottom of the basin had been excavated by the water, so that the piling had parted from the masonry of the apron. On the 23d of November the water was pumped out of the chamber, when it was found that a large part of the floor had been torn up, and the concrete and piles laid bare in several places. It became clear that the action of the sluices was attended not only with much inconvenience and hindrance to business, but also with a considerable amount of danger. In fact, so unmanageable were these sluices, with a head of only 14 feet 3 inches of water, which gave to the issuing current a velocity of twenty miles per hour, that the low-water basin, on which £470,252 had been spent, had to be abandoned and converted into a wet dock.

It is true that Mr. Rendel, the original designer of the sluices in question, was unfortunately no longer surviving to carry out his plans. But the law of the flow of water from an orifice under a definite head is so well known that it is not to be thought possible that the velocity of the current exceeded that anticipated. What was wanting was experience as to the inability of even the most carefully-constructed masonry to resist the effects of such a flow of water. From this point of view the failure of the Birkenhead sluices is highly instructive.

Scarcely less significant were the casualties that occurred in 1855, during the construction of the Victoria Docks, designed and executed by Mr. Bidder. These docks are entered from the Thames through a lock 80 feet wide at the bottom, 326 feet 6 inches long from gate to gate, and with a depth of 10 feet on the cill at low water. The walls of the dock are of concrete, faced with piling, and 20 feet thick at the bottom. The portion of the chamber containing the gates is of brickwork, and the bottom between the walls is lined with 7 feet 6 inches of concrete, or with 6 feet of brickwork. The top of this continuous invert is 25 feet 6 inches below Trinity high-water mark. On Sunday, 17th June, 1855, great progress had been made on the works; the upper and lower gates had been lifted into their places, the caisson was nearly completed, the bottom of the large dock of 74 acres had been puddled; and the removal of the river bank, and dredging at the entrance, was nearly all that remained to be done. There had been no symptom of weakness, nor any premonition of what was about to take place, except that on the previous day some joints in the coping on the south side were observed to be a little open, but to so slight an extent that the circumstance was not reported. The next day, however, in the afternoon, the portion of the north side between the upper and lower gates began to give way, moving forward bodily into the lock, pushing up the thick puddle towards the center, bending and breaking the tie bars behind, dragging the tie piles forward, and, in some instances, breaking them off. A few hours afterwards the south side failed in the same way, but the brick walls and platforms remained intact.

This large and sudden failure was accounted for (Proc. Inst. C. E., vol. xviii., p. 463) on the ground that the continuous pumping which had been carried on for two years, night and day, in order to get in the foundations of the lock walls, had drained the country over a considerable area. The water in a well at a distance of $2\frac{1}{4}$ miles from the docks had been lowered during this pumping, and rose when it ceased. At the time of the accident the pumping had been discontinued for some weeks, and 3 feet of

water had been allowed to collect in the dock, to test the puddle. It was excluded from the lock chamber, and it was thought that the hydraulic pressure accumulated at the back of the wall, and forced them bodily inwards. Fractures of the pivot casting, and abrasion and splitting of the roller-path, also took place.

The Avonmouth Dock was designed by Mr. Brunlees; commenced in August, 1868, and opened for traffic in February, 1877. It has an area of 16 acres, being 1,400 feet long and 500 feet wide, and is entered from the Severn by a lock, which has a clear length of 454 feet between the inner and outer gates, and is 70 feet in width. The range of tide for which the gates have to provide is 43 feet 10 inches; the width of the dock wall at the base, 2 feet above the dock floor, is 16 feet, and the width at the top is 10 feet 6 inches. When about 247 lineal yards of this section of wall had been built up to the level of the coping, and the backing was well advanced, a failure of about 90 yards occurred. The wall broke through from top to bottom in the middle of this distance, slid forward 12 feet, and sank 4 feet 6 inches. Where not affected by this slip, the wall showed no tendency to slide out of place, but an inclination to overturn by coming forward at the top. It was built with a batter of 3 feet 4 inches from floor to coping, but when the forward movement ceased, the batter measured only 1 foot 4 inches. The part of the wall that slipped forward maintained its original batter.

When the east wall was finished and backed up to nearly its full height, and within a few days from the date fixed for letting water into the dock, a subsidence of about 140 yards of the most recently completed portion took place. The movement was of a similar kind to that which had occurred on the opposite side. At the apex or breach, the wall slipped forward 15 feet 6 inches, and sank 7 feet 6 inches. The dock floor in front was thrown up 10 feet in height for a distance of about 60 feet. The breach in the wall was much larger than in the other case, and extended through the foundations. This portion of the wall was founded at an average depth of 9 feet below the bottom of the dock, and the whole of the foundation moved forward with the slip. Both accidents occurred on a Sunday night, when no men were at work, and two hours before the occurrence of the latter failures nothing unusual was to be seen in the wall.

In the discussion which took place on the Avonmouth Dock at the Institution of Civil Engineers on December 12, 1878, Mr. Walmsley Stanley remarked that before designing the walls of a dock, the exact nature of the strata on the line, and for some distance on each side of the walls, should have been ascertained. He regarded the foundation for the docks at Avonmouth as exceptionally good. They rest on a bed of fine grey sand underlying the clay at an almost uniform level throughout its length, and at a depth of 6 feet below low water of equinoctial spring tides. The trial borings were only carried 10 feet deeper, and the pile-driving gave no signs that the sand had been passed through at a depth of 25 feet. Springs were frequent in this sand. A layer of 6 inches of clay had been sufficient to keep these down, but when this was removed they burst out in various places, and in some had to be provided with permanent outlets. The question is very pertinent. "Were these failures through any new elements of danger, or new combination of elements, or did they arise from want of proper examination before the design and execution of the work?" Whatever reply be given to this question the special study that is requisite for works of the kind is abundantly proved by these serious failures.

In the year 1864 it was found necessary to extend the dock accommodation at Belfast. The foundation for the wall of the new Abercorn basin was firm sand, so that it was not considered necessary to do more than drive in front of the wall a close row of sheet piles, 12 feet long and 6 inches thick. At the Dufferin and Spencer docks the substrata were soft and unreliable, and 15 feet bearing piles of round larch were introduced. Battens and sleepers were laid on the heads of these piles, and covered with 18 inches of concrete, on which the masonry, 16 feet in width at the bottom, was built. These walls showed weakness from the first. As the backing proceeded, the symptoms became more seri-

ous. Two years after the erection of the entrance to the Spencer tidal dock, a length of 70 yards of the wall fell bodily forward into the entrance. It fell outwards at the top, pivoting on its toe, and broke the bearing piles across about their middle, 6 feet or 7 feet below the bottom of the wall. The sleepers, concrete, and tops of the piles adhered to the masonry, which had to be removed by divers. The nature of the backing used, which seems to have exerted on the back of the wall a semi-fluid pressure perhaps double of that due to hydraulic head, together with the soft foundation, are enough to account for the Belfast failures. Still the same question recurs: Was not the nature of these materials known beforehand? and should they not have been more skillfully dealt with?

Closely combined with the important question of the security of the foundation of hydraulic works is that of the true principles on which their dimensions should be determined. While adequate size is demanded by the exigencies of traffic, any undue or unused excess of dimensions is at the same time a cause of increased cost and of increased risk. In hydraulic works the ruling dimensions must be determined in consistence with those of the craft which it is intended to accommodate. As to this, the present course of shipbuilding is, to some extent, in favor of restricted rather than of increased width, although in those dimensions which provide for the length of craft there is advance rather than decline. The gates of the Canada Dock at Liverpool, 100 feet wide, were constructed for paddle-box steamers. So great a width is not needful for a screw-ship. It is plain that the extreme dimensions in length, breadth, and width, plus a certain allowance for clearance, of the craft which it is designed to accommodate, should be taken as the ruling dimensions for hydraulic works. For locks, a foot or two of clearance in each direction may suffice; for docks, basins and canals, 25 per cent. of width and depth will hardly be too much to allow for clearance. Room in excess of this will involve waste. The present proportions used by shipbuilders give from eight to ten beams to the length, and locks that are not in this proportion either for one or for a pair of vessels involve great waste, both in construction and in supply of water. Thus the 454 feet lock at Avonmouth could accommodate the largest vessel that is now likely to pass it, if it were 45 feet, or at the utmost, 50 feet wide. A dock entering from the tideway can hardly be expected to admit two vessels at a time, convenient as this arrangement is on a canal; but if two vessels, say of 38 feet beam, were docked at the same time at Avonmouth, there would be a useless length of 50 feet or 60 feet in the lock.

The want of intelligent foresight in the adoption of dimensions that shall be adequate, and not more than adequate, for the work that a structure is intended to facilitate, is remarkably evinced in the dimensions of our canal locks. Thus the line of canal communication between the water of the Thames and that of the Trent is made by two different lines. A boat arriving at Northampton by the Grand Junction Canal has to use the Grand Union Canal in order to go on to Leicester. But while the locks on the Grand Junction are 87 feet 6 inches long, and 15 feet wide, those on the Grand Union are only 78 feet long, and 7 feet 2 inches wide. As to the width, it may be urged that the narrow locks will admit a single boat, while the wide lock will admit either a barge or a pair of boats of the same width as will pass, singly, through the narrow lock. But as to length there is a positive discrepancy. A boat built for the Grand Junction lock will not pass through the Grand Union lock. A boat built for the latter, if it pass on the former canal, loses 10 or 15 per cent. in capacity, and involves a corresponding unnecessary loss of water at each lockage.

In no case is this absence of proper engineering consideration more conspicuous than in that of the Suez Canal. After an expenditure of £20,000,000 on a water way of eighty-eight geographical miles in length, extreme difficulty is felt in passing a traffic of 7,000,000 tons of shipping through the canal in a year. In 1882, 3,198 ships, of an average tonnage of 2,150 tons each, made the transit of the canal. This is not quite nine vessels per day, and yet it has been decided to expend a million sterling on the inefficient palliatives of intermediate basins. "For all steam ships, or vessels towed,

varying between 280 feet and 300 feet in length," reported the Hydrographer to the Navy, in February, 1870, "with 35 feet beam, and a draught of 20 feet, it will, with the improvements and appliances earlier described, be a convenient highway....For the transit of vessels larger than those described, the canal is not so well adapted." That the Indian transports, of "about 400 feet long, with a draught of 22 feet of water, and beam of nearly 50 feet, can pass through the canal is undeniable; but no practical seaman need be told that in steering through what may be called a continuous dock ninety miles in length, less than 100 feet wide, and with nothing showing above water to mark the center of it, frequent grounding and consequent delay may be anticipated, though every possible care and precaution be taken. It is to be considered, also, that the midship section of one of these vessels bears about an average proportion of 1 to 4 to the deep water of the canal."

And yet the cross section of the Suez Canal, according to the final determination, contains 3,862 square feet beneath the water line. The midship section of H. M. S. Warrior is 1,219 square feet. This is a much closer fit than the proportion named by the Hydrographer to the Navy. The Warrior made one of the fastest passages on record through the canal, viz., in 12 hours 50 minutes. But her speed at sea was 14.35 knots per hour. But of the entire cross section of the canal, not more, in many parts, than 66 per cent. is in any way available for navigation. The only function performed by at least one third of the area is that of allowing the water displaced by the passage of a vessel to return to the wake of the same, or that of the protection of the banks from wash (as to the latter, however, revetting with stone is being partially carried out). The passage of vessels is restricted to a speed of five knots, and no two vessels are allowed to cross in the canal unless one of them be moored in a lay-by.

Of these "gares," or passing places, there are fourteen. It will thus be seen that thirty vessels are the utmost that can at one time be in course of transit through the canal, viz., fifteen under steam and fifteen in the lay-byes or terminal basin. At five miles an hour (and allowing only twelve hours in the day) it would thus take nearly two days to go through 100 miles of canal. But, as for half the time of transit, the vessels are in the lay-byes, the speed is reduced to 2½ knots, and the time of passage is extended to four days. Hence the just complaints of the shipping trade.

By the use of a scientific cross section, of equal area to that actually excavated, but with revetted sides, the capacity of the Suez Canal would have been increased in a proportion which it may seem fabulous to state. In the first place two 2.000-ton vessels would have been able to pass one another in any part of the canal, the vessel which had the wind against her slacking or stopping for the time of passing. This would at once raise the capacity of the canal from 30 to 200 vessels—as a line of ships might follow one another, in each direction, with perfect ease a mile apart. In the second place the time consumed in passing would have been reduced by one-half; as no time would be lost in lay-byes. In the third place the cost of propulsion would have been reduced, as the hydraulic mean depth of the scientifically designed canal (the area of water divided by the wetted perimeter) which is taken by hydraulicians as a measure of resistance, is double that of the actual cross-section. And in the fourth place, as a curved bottom would be substituted for the present flat bottom, vessels of 4 feet more draught than could pass the French canal could pass one constructed with the true hydraulic cross-section.

Important as these considerations are to the shareholders who have sanctioned the expenditure of another million for the construction of intermediate basins, which will little, if at all, increase the actual capacity of the canal for traffic, as above shown, we have but little hope that any remonstrance expressed in the English language will be likely to reach them. But if traffic is impeded by the contempt shown by politicians for hydraulic rules, it is to be hoped that this will not be altogether the case in England. Not a week now passes without signs of the revival of the public interest in canals. What has been done in England by canals is now being investigated; and the return of a certain portion of traffic

to these cheap and silent high roads is now anticipated by every writer who touches on the subject.

Since the days of Brindley and of Telford great advance has been made in mechanical and in hydraulic knowledge. It is sufficient to compare the experiments of Mr. Froude, as they are described in volume xviii. of the Transactions of the Institution of Naval Architects, with those of Mr. Palmer and Sir John MacNeill, as described in volume i. of the Transactions of the Institution of Civil Engineers, to see how much has been done to determine the true dimensions of vessels, and how little has been done to determine the true dimensions of canals.

According to the formulæ now accepted, the resistance to the passage of a vessel through the Suez Canal is just double that which would be encountered if the cross section, when of the same area, was of a better shape. We do not say that this is the case—we only say that it is so according to the accepted formulæ. But with millions in the course of expenditure on the waterways of Europe, is it not lamentable that we should have to look in vain for the inauguration of those experiments, for the guidance of the hydraulic architect and engineer, of which every member of the profession who has turned his attention to the subject at once acknowledges the importance and deplores the absence?

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## RESISTANCE ON RAILWAY CURVES AS AN ELEMENT OF DANGER.

By JOHN MACKENZIE, Assoc. M. Inst. C. E.

From Proceedings of the Institution of Civil Engineers.

The friction caused by the unequal and indirect action of the wheels of a locomotive engine or carriage on curved rails is a source of additional tractional resistance, and also of a considerable amount of danger, from the tendency of the wheels to run off the rails; and it is entirely with regard to this danger that the subject is treated in this paper.

On looking over the Board of Trade Returns of Railway Accidents for several years, it will be found, in most of the cases in which engines left the rails without a tolerably obvious cause, that the engines were six-wheeled with parallel axles, and in some cases were running at low speeds; indeed in one case the speed was so low that the centrifugal force was more than balanced by the cant of the rails, so that some other agency than centrifugal force was evidently at work.

The tendency which a wheel has to mount the rail on a curve is evidently caused by the adhesion or friction between the rail and the flange of the wheel, and this adhesion will bear some proportion to the side pressure with which the flange is forced against the rail. In the case of the wheel most likely to mount the rail, namely the outer leading wheel, this side pressure, at low speeds, is principally caused by the resistance which the treads of the wheels oppose to the sliding motion which takes place in running round a curve.

Taking the case of an engine with six cylindrical wheels on three parallel axles, all coupled, the middle or driving axle being midway between the other two: when such an engine is running on a curve, and the clearance is the least possible, so that the flanges of the wheels just fill the space between the rails, then the driving axle is radial, the wheels on the leading axle tend to run outwards, and those on the trailing axle to run inwards.

The flange of the outer leading wheel is pressed hard against the rail. The flange of the inner driving wheel is parallel to the rail, and has of itself no tendency to press against it, but is kept close to it by the trailing wheels: the outer trailing wheel, although the flange is kept close to the rail by the outer leading and inner driving wheels, has a tendency to leave the rail; and the inner trailing wheel, notwithstanding the tendency to run against the rail, has the flange

kept clear of it by the outer leading and inner driving wheels.

When the coning of the wheels exactly suits the curve, the leading wheels, and in this case the trailing wheels, do not slide along but only across the rails; but the sliding of the driving wheels is increased if the wheels are coned, unless indeed they are coned in the opposite direction to the others.

When the clearance between the rails and the flanges of the wheels is increased to just a sufficient extent to allow the inner trailing-wheel flange to run against the rail then the driving axle is not radial, but has the inner end slightly in advance of a radial line, and the trailing axle has the inner end slightly behind a radial line, and the sliding motions of the wheels take place round a point P, situated between the driving and the trailing wheels. In this case the sliding of the trailing, as well as of the driving, wheels is increased if the treads of the wheels are conical.

When the clearance is increased, or the radius of the curve increased, to a still further extent sufficient to allow the inner trailing wheel to run with the flange just clear of the rail, then the position which the engine takes up on the rails depends somewhat upon the comparative loads on the wheels. The driving wheels, in following the leading wheels have a tendency to assume a position with their axis radial; but the trailing wheels have the same tendency, and it is impossible that both axles can be radial. If one pair of wheels is much more heavily loaded than the other, the more heavily loaded pair will run with the axis radial, but the tendency of the trailing wheels to run forward is increased by the tendency of all the inner wheels to outrun the outer ones, so probably the trailing axle is generally radial, and the sliding motions of the wheels take place round a point situated where the inner wheel touches the rail.

In order to cause these sliding motions, the outer leading-wheel flange exerts against the rail a pressure sufficient to overcome the adhesion or friction of the treads of the wheels; this pressure being exerted directly on the leading wheels, and transmitted to the other wheels through the medium of the engine framing acting as a lever with its fulcrum at the point of contact.

The resistance which a wheel opposes to sliding across the rail probably does not differ much from its adhesion for traction; and the pressure exerted by the leading-wheel flange to overcome this resistance or adhesion will, for each wheel, be approximately equal to the adhesion of that wheel multiplied by its distance from the wheel which acts as fulcrum, and divided by the distance of the leading axle from the axle on which is the wheel acting as fulcrum. These pressures being taken for each wheel, the sum of them will be the total side pressure on the outer leading-wheel flange.

When the flange of the outer leading wheel is on the point of mounting the rail, the tread, being relieved of pressure and adhesion, need not be taken into account in estimating the pressure on the flange.

The distances which the several wheels slide vary with the sharpness of the curve, but the adhesion remains constant; so that although the energy expended in causing the wheels to slide while the engine runs a certain distance along the rails increases with the sharpness of the curve, the pressure in the line of the axle required to effect this sliding is nearly constant, whatever may be the radius of the curve. The pressure exerted by the flange on the rail is, however, slightly greater than that in the line of the axle, as that line is not at right angles to the rails, and this pressure increases as the secant of the angle at which the wheel stands on the rails. As this angle can never in practice exceed 2° 30′, and the secant of 2° 30′ does not exceed the radius by one-thousandth part of its length, the additional pressure arising from increasing sharpness of curve may be neglected.

On a curve the point of contact between the outer leading-wheel flange and the rail is in advance of a perpendicular from the wheel's axis, so that the motion of the wheel at that point is downward, imparting a downward pressure to the rail, and an upward pressure to the wheel. Thus, when the adhesion between the flange and the rail is greater than the weight upon the wheel, the flange would rise and mount the rail even if the surfaces at the point of contact were ver-

tical; and when they are inclined (as they always are), the tendency of the wheel to rise is augmented.

Owing to the downward motion of the flange at the point of contact, the side pressure required to cause the flange to mount the rail is, not the pressure which, when the wheel is at rest, would force it over the rail in opposition to friction as well as to gravitation, but the very much smaller pressure which, when the wheel is at rest and the tread slightly raised above the rail, would cause friction sufficient to prevent its falling into its place again.

With a wheel and rail whose surfaces at the point of contact do not appreciably vary from the vertical, the wheel would be caused to mount the rail by a side pressure bearing the same proportion to the load on the wheel which the oad bears to the adhesion.

When the surfaces at the point of contact are inclined (as they always are), the pressure required to cause the wheel to mount the rail diminishes rapidly as the angle of inclination increases; as with an angle flatter than that down which the one surface would just slide on the other, the flange, if raised, would not slide back into its place even if there were no side pressure.

When the outer leading wheel begins to rise, the increasing deflection of the spring opposes a greater resistance to its rising further. This tendency to rise, while the conical part of the flange touches the rail, is nearly constant so long as the proportion of adhesion to pressure is constant; but if this proportion raises the wheel to such an extent that the rounded edge of the flange begins to come into contact with the rounded corner of the rail, the tendency to rise increases more rapidly than the resistance of the spring, and the wheel, which has then passed its maximum of stability, mounts the rail.

The higher tension of the spring adds to the load on the outer leading wheel, and at the same time raises the center of gravity of the engine, and alters the distribution of the remaining weight on the other wheels, this redistribution varying with different arrangements and proportions of springs.

It has not been proved experimentally whether the friction of the flange against the rounded corner of the rail is the same, in proportion to the pressure, as is that of the tread against the crown of the rail. The surface of a cylindrical tread may run on a straight rail without any sliding motion whatever; but the highly inclined surface of the flange can never run against the rounded corner of the rail without some portion of even the very small surfaces in contact sliding. It is therefore possible that the flange-friction partakes of the nature of the friction of a skidded wheel, or of a wheel against a brake-block which has been found to diminish at high velocities; and this possibility is almost rendered a probability by the circumstance that, of the cases reported of engines leaving the rails, comparatively few occurred at high speeds. This is the most doubtful part of the question; or rather it is the only really doubtful point; the rest is a mere mechanical problem, but an extremely complicated one. In the absence of information on this point, it will be assumed that, at moderate velocities, the flange friction bears the same proportion to the pressure as does the adhesion of the tread, and that the two vary together when the state of the rails varies. This being so, with a doubled coefficient of friction the side pressure on the leading-wheel flange, required to make the other wheels slide, is doubled: at the same time the proportion which the flange's own adhesion bears to that side pressure is also doubled, so that the adhesion of the flange is fourfold. In other words, the tendency to mount the rail increases as the square of the fraction representing the coefficient of adhesion; or rather it would increase in this ratio if the surfaces were vertical, but when they are inclined the ratio is less rapid.

When the leading flange is lubricated, its friction is nearly constant, so that the tendency to rise increases only in the simple ratio of the adhesion, instead of in the duplicate ratio.

It is evident that if there were no friction between the rails and the treads and flanges of the wheels, the outer leading wheel, when running slowly on a curve, would have no tendency to mount the rail; and it is equally evident that if the friction were infinitely, or very, great, the engine would run straight forward over the rails. Between these extremes there

must be a certain proportion of friction which will just balance the weight on the wheel, and any addition to this friction would cause the wheel to rise over the rail. This differs in different engines; and if for any engine the proportion of friction which will cause it to leave the line is one that may occur in certain conditions of the rails, then that engine is dangerous in the extreme; and any engine is so to some extent, which has not, in this as in other respects, a considerable margin of safety.

Captain Douglas Galton, Assoc. Inst. C. E., in giving the results of his experiments on the adhesion between wheels and rails, states that, "On dry rails it was found that the coefficient of adhesion of the wheels was generally over 0.20. In some cases it rose to 0.25 or even higher. On wet or greasy rails, without sand, it fell as low as 0.15 in one experiment, but averaged about 0.18. With the use of sand on wet rails it was above 0.20 at all times; and when the sand was applied at the moment of starting, so that the wind of the rotating wheels did not tend to blow it away, it rose up to 0.35, and even above 0 40."

Thus an engine could not be considered safe if, when the adhesion rose to 40 per cent. of the weight, the side pressure on the flange of the leading wheel were sufficient to prevent the flange, when raised, from sliding down again on the side of the rail.

To apply the foregoing to the case of an engine which actually left the rails, the following example may be taken from the Board of Trade Returns as to railway accidents, where the circumstances are thus reported: "The branch leaves the main line on a curve to the right, with a radius of only 640 feet. . . . There is a cant of 2¼ inches. The engine is a four-wheel-coupled tender engine, with a wheel base of 14 feet 4 inches. The weights on the three pairs of wheels are—

| | Tons. | cwt. |
|---|---|---|
| "On leading wheels..... | 7 | 8 |
| " driving " ..... | 10 | 13 |
| " trailing " ..... | 7 | 12 |
| Total..... | 25 | 13 |

"The engine itself is in good order, and there is no reason to attribute the accident to any fault in the rolling stock. The speed was, no doubt, as much as 15 miles an hour, the authorized speed, but . . . there is no reason for supposing that this speed was exceeded.

"The road did not gauge very evenly from the facing points southward, being in some places as much as $\frac{2}{16}$ inch slack, and in others exact to gauge."

The Inspector goes on to say: "I am of opinion that this accident was due to the want of a proper check-rail at this curve of under 10 chains radius, and to the somewhat slack state of the permanent way."

Assuming that each wheel had an independent spring which (not to overestimate the danger) may be assumed to have been stiff enough to deflect only 2 inches with its usual load; and that the driving axle, with its wheels, weighed 1½ tons, and the leading and trailing axles, with their wheels, 1 ton each; and that the outer leading wheel rose ½ inch before the rounded edge of the flange came into contact with the rail,—then this additional deflection of its spring probably increased the load on this wheel to about 4 tons 1 cwt., and caused the remaining weight to be distributed on the other wheels somewhat as follows, namely:

| | Tons. | cwt. |
|---|---|---|
| On the inner leading wheel..... | 3 | 10 |
| " outer driving " ..... | 5 | 0 |
| " inner " " ..... | 5 | 7 |
| " outer trailing " ..... | 3 | 15 |
| " inner " " ..... | 4 | 0 |

Assuming that the inner driving-wheel flange was pressed against the rail, and also, as a preliminary, that the adhesion was ⅕ of the weight, the pressure exerted by the outer leading-wheel flange in causing the treads of the outer wheels to slide on the rails (its own tread being lifted clear of the rail), was probably:

| | Ton. |
|---|---|
| For the outer leading wheel $=0.0(4.05\times7.16=29=N)$ | $=0.0000$ |
| " the inner leading wheel $=0.2(3.5\times71.6=25.060)\div7.16$ | $=0.7000$ |
| " the outer driving wheel $=0.2(5.0\times4.916=24.580)\div7.16$ | $=0.6866$ |
| " the inner driving wheel $=0.2(5.35\times0.00=0.000)\div7.16$ | $=0.0000$ |
| " the outer trailing wheel $=0.2(3.75\times8\ 61=32.287)\div7.16$ | $=0.9018$ |
| " the inner trailing wheel $=0.2(4.00\times7.16=28.640)\div7.16$ | $=0.8000$ |

$M=110.567$ foot-tons.

$15\ 44=110.567\div7.16$

$0.2\times15.44=$ tons 3.0884

or say a little over 3 tons.

Next, assuming that the flange formed an angle of 75° with a horizontal plane, or 15° from the vertical, then, with an adhesion of $\frac{1}{5}$, the load of 4 tons 1 cwt. on the outer leading wheel would prevent its rising unless forced against the rail by a side pressure equal to:

$\frac{1}{5}=0{\cdot}2=$cotangent 78° 41′; then

Tangent $(78°\,41'-15°\,0')\times 4.05$ tons
$=2.02\times 4.05=8.18$ tons or, say,

8¼ tons, or nearly three times the side pressure which would cause the other wheels to slide; so that with this proportion of adhesion, there would have been a considerable margin of safety unless other forces were at work.

It is uncertain from the report whether or not the steam was shut off when the engine left the rails; but in order to leave the case as simple as possible, it will be assumed that it was so, and that the engine was exerting no tractive force.

Taking the speed at 15 miles an hour, or 22 feet per second, the centrifugal force was:

$$\frac{25.65\times 22^2}{32\times 640\text{ feet}}\ \begin{matrix}\text{Tons.}\\ \text{Ton.}\end{matrix}=0.606.$$

or only about 12 cwt., which was considerably more than counteracted by the cant of 2¼ inches; the inward force due to which was

$$\frac{2\frac{1}{4}\text{ inches}\times 25{\cdot}66\text{ tons}}{59\text{ inches}}=0.97\text{ tons.}$$

or slightly exceeding 19 cwt., being about 7 cwt. more than the centrifugal force. As indicated by the loads on the wheels, the center of gravity was about ½ inch behind the center of the driving axle; so, assuming the inner driving-wheel flange to have been pressed against the rail, the excess of cant would have thrown on the outer leading-wheel flange a side pressure of

86 inches : ½ inch :: 7 cwt. : 0.04.,

or about 5 lbs., which need not be taken into consideration. To this small extent, however, the engine would have been less likely to have left the rails had it been running at the speed at which the cant would balance the centrifugal force. There is no probability that the engine was running at the very high speed at which the centrifugal force, after counteracting the cant, would have been sufficient to cause the flange to adhere: the accident cannot be accounted for under the conditions mentioned.

Assuming, however, that the adhesion, instead of $\frac{1}{5}$, or 20 per cent., had been 37 per cent. of the weight: then in order to cause the other wheels to slide, the outer leading-wheel flange would have required to exert a side pressure equal to

$$0.37\times 15.44=5.7\text{ tons.}$$

or about 5 tons 14 cwt.; and this side pressure is just equal to that which, with 37 per cent. of adhesion, would cause the flange to adhere and rise over the rail, namely,

0.37 being cotangent of 69° 42′,

Tangent $(69°\ 42'-15°)\times 4.05$ tons
$=1.41\times 4.05=5.7$ tons, 5 tons 14 cwt.

Thus the accident might have been caused by the rails being in such a condition that the adhesion was 37 per cent. of the weight, assuming that it happened at a place where the gauge was sufficiently tight to allow the flange of the inner driving wheel to come into contact with the rail before that of the inner trailing wheel. This might have been the case, as the curvature of the rail in the length of the wheel base amounted to about ½ inch.

The tractive force, the centrifugal force, and the cant have been left out of consideration, as their effect in this case was so small as hardly to influence the result.

It may have been noticed that the coefficient of the friction which would just cause the flange to adhere and mount the rail was assumed to be 37 per cent. in order more easily to explain the process of calculation, as the formula for ascertaining this coefficient is somewhat long, though quite elementary, being

$$\frac{N}{\left(\tan a\times\frac{M+N}{2\cos a}\right)\times\sqrt{\left(\frac{M+N}{2\cos a}\times\frac{M-N}{2}\right)\times\left(\frac{M+N}{2\cos a}-\frac{M+N}{2}\right)}}=\text{coefficient,}$$

where N = product of the weight on the outer leading wheel multiplied by its distance from the wheel acting as fulcrum.

M = sum of the similar products of all the other wheels; and

$a$ = angle formed by the working face of the flange and the plane of the wheel.

In the case in question—

N = 29 foot-lbs.

M = 110.567 foot-lbs.

$a = 15°$; and

$$\frac{29}{(\tan 15° \times 69.78) + \sqrt{\left(\frac{69.78}{\cos 15°} + 40.78\right) \times \left(\frac{69.78}{\cos 15°} - 40.78\right)}} = 0.37.$$

The foregoing case was selected for an example as being comparatively free from disturbing elements, and not on account of the percentage of friction causing the engine to leave the rails being exceptionally low. In another accident reported on, adhesion would have been less than 36 per cent. if the engine had been tight to gauge and about 46 per cent, if slack. In this last case the Inspector considered that the accident was due partly to some defect in the permanent way, and partly to the load on the wheel which left the rail being less than on the other wheels, the load on the leading wheels being 8 tons 12 cwt., on the driving wheels 12 tons 13 cwt., and on the trailing wheels 10 tons.

The following tables are calculated, as far as possible, exactly in a similar manner to the case given as an example, and are merely intended to indicate the com-

INFLUENCE OF DISTRIBUTION OF LOAD ON THE COEFFICIENT OF DERAILING ADHESION.

| Normal Load on | | | Tight to Gauge, with Inner Driving-wheel Flange touching Rail. | | | Slack to Gauge, with Inner Trailing-wheel Flange touching Rail; or with Flangeless Driving Wheels. | | |
|---|---|---|---|---|---|---|---|---|
| Leading Axle. | Driving Axle. | Trailing Axle. | Coefficient of Derailing Adhesion. | Coefficient of Derailing Adhesion with Flanges, lubricated. | Additional Tractional Resistance due to curve of 5 chains radius, in lbs. per ton, with adhesion = one-fifth of load. | Coefficient of Derailing Adhesion. | Coefficient of Derailing Adhesion, with Flanges lubricated. | Additional Tractional Resistance due to curve of 5 chains radius, in lbs. per ton, with adhesion = one-fifth of load. |
| Tons. | Tons. | Tons. | | | Lbs. | | | Lbs. |
| 1 | 28 | 1 | 0 12 | 0.10 | 4.48 | With these loads the adhesion of the driving wheels prevents the trailing-wheel flange from touching the rail. | | |
| 2 | 26 | 2 | 0.18 | 0.19 | 4.96 | | | |
| 3 | 24 | 3 | 0.24 | 0.28 | 5.47 | | | |
| 4 | 22 | 4 | 0.28 | 0 35 | 5.98 | | | |
| 5 | 20 | 5 | 0.31 | 0.41 | 6.50 | | | |
| 6 | 18 | 6 | 0.33 | 0.47 | 7.05 | | | |
| 7 | 16 | 7 | 0.35 | 0.51 | 7.58 | 0.40 | 0.63 | 9.56 |
| 8 | 14 | 8 | 0.36 | 0 55 | 8.11 | 0.44 | 0.75 | 9.85 |
| 9 | 12 | 9 | 0.38 | 0.58 | 8.64 | 0.48 | 0.87 | 10.11 |
| 10 | 10 | 10 | 0.39 | 0.61 | 9 20 | 0.52 | 1.00 | 10.50 |
| 11 | 8 | 11 | 0.40 | 0.64 | 9 74 | 0.55 | 1.14 | 10.84 |
| 12 | 6 | 12 | 0.41 | 0.66 | 10.28 | 0.59 | 1.28 | 11.23 |
| 13 | 4 | 13 | 0.41 | 0.67 | 10 82 | 0.63 | 1.43 | 11.35 |
| 14 | 2 | 14 | 0.42 | 0.70 | 11.35 | 0.66 | 1.61 | 11.79 |
| 15 | 0 | 15 | = four wheels. | | | 0.70 | 1.79 | 11.99 |
| 8 | 14 | 8 | 0 36 | 0.55 | 8.11 | 0.44 | 0.75 | 9.85 |
| 8 | 11 | 11 | 0.34 | 0.48 | 9.00 | 0.46 | 0.82 | 9.92 |
| 8 | 8 | 14 | 0.32 | 0.43 | 9.90 | 0.49 | 0.90 | 9.89 |

INFLUENCE OF THE WIDTH OF GAUGE ON THE DERAILING ADHESION.

| Width of Gauge. | Coefficient of Derailing Adhesion. | |
|---|---|---|
| | Tight to Gauge, with Inner Driving-wheel Flange touching the Rail. | Slack to Gauge, with Inner Trailing-wheel Flange touching Rail, or with flangeless Driving Wheels. |
| Feet. Inches. | | |
| 2 0 | 0 42 | 0.55 |
| 3 0 | 0.41 | 0.54 |
| 4 8½ | 0.39 | 0.52 |
| 7 0 | 0 36 | 0.49 |
| 35 0 | 0.20 | 0.29 |
| 75 0 | .. | 0.20 |

INFLUENCE OF THE LENGTH OF WHEEL-BASE ON DERAILING ADHESION ON A CURVE OF 5 CHAINS (330 FEET) RADIUS.

| Length of Wheel-base. | Coefficient of Derailing Adhesion. | |
|---|---|---|
| | Tight to Gauge, with Inner Driving-wheel Flange touching the Rail. | Slack to Gauge, with Inner Trailing-wheel Flange touching Rail, or with flangeless Driving Wheels. |
| Feet. | | |
| 1 | .. | 0.20 |
| 2 | 0.20 | 0.29 |
| 5 | 0.29 | 0 41 |
| 10 | 0.36 | 0.49 |
| 12 | 0.38 | 0.50 |
| 15 | 0.39 | 0.52 |
| 20 | 0.40 | 0.53 |
| 25 | 0.41 | 0.52 |
| 30 | 0.42 | 0.52 |
| 35 | 0.42 | 0 50 |
| 40 | 0.41 | 0.48 |
| 50 | 0 40 | .. |
| 200 | 0.20 | 0.20 |

parative influences which variations in the proportions of an engine have in increasing or diminishing its tendency to leave the rails. These influences are measured by the coefficient of the friction which will just cause the flange of the outer leading wheel to adhere and mount the rail, referred to in the tables as the "coefficient of derailing adhesion."

INFLUENCE OF THE NUMBER OF WHEELS ON THE DERAILING ADHESION.

| Number of Wheels. | Coefficient of Derailing Adhesion. | |
|---|---|---|
| | Tight to Gauge, with the Flange of the Inner Wheel in the middle, or nearest the middle, of the length touching the Rail. | Slack to Gauge. |
| 4 | 0.70 | 0.70 |
| 6 | 0.39 | 0.52 |
| 8 | 0.39 | 0.39 |
| 10 | 0.29 | 0.35 |
| 18 | 0.20 | 0.24 |

It will be noticed that the danger is greatest in engines which have an axle in the middle of the length of their wheel-base.

INFLUENCE OF THE ANGLE OF FLANGE ON THE DERAILING ADHESION

| Complement of the Angle between the working face of the Flange and a horizontal Plane. | Coefficient of Derailing Adhesion. | |
|---|---|---|
| | Tight to Gauge, with Inner Driving-wheel Flange touching the Rail. | Slack to Gauge, with Inner Trailing-wheel Flange touching Rail, or with flangeless Driving Wheels. |
| ° ′ | | |
| 0 0 | 0.53 | 0.68 |
| 5 0 | 0.48 | 0.62 |
| 10 0 | 0.43 | 0.56 |
| 15 0 | 0.39 | 0.51 |
| 16 30 | 0.37 | 0.50 |
| 20 0 | 0.35 | 0.46 |
| 22 30 | 0.33 | 0.44 |
| 25 0 | 0.31 | 0.42 |
| 30 0 | 0.28 | 0.38 |
| 35 0 | 0.25 | 0.34 |
| 40 0 | 0.22 | 0.30 |
| 45 0 | 0.19 | 0 27 |
| 50 0 | .. | 0.23 |
| 55 0 | .. | 0.20 |

The engine is supposed in all cases to weigh 30 tons. Where not otherwise stated, and not inconsistent with the other particulars, this weight is considered, when the wheels are level, to be equally distributed on the treads of six

coupled wheels 4 feet in diameter; the leading axle with its wheels weighing 1 ton, the driving axle and wheels 1½ ton, and the trailing axle and wheels 1 ton, the deflection of each of the springs with its ordinary load being 2 inches. The load stated in the tables is this normal load, and not the load as altered by the rising of the outer leading wheel; but the alteration caused by this rising is allowed for as before.

Similarly the wheel base is taken as 15 feet, the gauge 4 feet 8½ inches, the angle between the face of the flange and the plane of the wheel 15°, and the treads of the wheels are assumed to be cylindrical.

In most cases the circumstances differ from the above in one particular only.

When described as "tight to gauge," the curve and clearance are supposed to be such that the inner driving-wheel flange touches the rail. Where described as "slack to gauge," the curve is supposed to be easy enough, or the clearance and end play of the bearings to be sufficiently great, to allow the inner trailing-wheel flange to touch the rail; or the driving wheels are supposed to be flangeless, which would have the same effect.

As it is particularly desired to avoid exaggerating the danger, the circumstances as above stated are perhaps rather more favorable than would usually exist; for instance, the springs would generally be deflected more than 2 inches, and the angle of most flanges probably exceeds 15°. The centrifugal force also would generally increase the tendency to mount the rail, and in some cases this tendency would be increased by high winds and by oscillations.

In most cases the proportions are carried, in the tables, to their extreme limit in one direction, being that at which the derailing adhesion becomes less than one-fifth of the load, or 0.20. As might have been expected, this limit is generally far beyond what occurs in practice.

Restricting the subject strictly to six-wheeled engines with parallel axles, and referring to such engines only, the following inferences may be drawn from the foregoing remarks:

1. That the danger of leaving the rails increases when the adhesion increases.

2. That the greater the portion of the weight of the engine resting on the leading wheels, the less is the danger of leaving the rails at low speeds.

3. That when tight to gauge the danger is increased to the greatest extent by augmenting the load on the trailing wheels, at low speeds.

4. That when slack to gauge, or the driving wheels flangeless, or the radius of the curve large, the greatest danger is brought about by increasing the load on the driving wheels.

5. That the danger increases when the radius of the curve decreases; but at low speeds, the danger increases very slowly, until the curvature becomes such that the inner driving-wheel flange is brought into contact with the rail, when the danger increases suddenly; and the danger is aggravated by tightness of gauge.

6. That this sudden increase of danger is obviated by making the driving wheels flangeless; and that flanges on the driving wheels are worse than useless.

7. That the danger increases when the gauge is widened in proportion to the length of the wheel-base.

8. The danger of leaving the rails diminishes when the length of wheel-base increases in proportion to the width of gauge; but when the length of wheel-base increases in proportion to the radius of the curve, the danger increases; so that there is a certain length of wheel-base giving a minimum of danger: but within the limits of practice, the longer the wheel-base, the less the danger of leaving the rails. Nevertheless the tractional resistance always increases with the wheel-base.

9. The danger is increased by increasing the number of wheels; but the tractional resistance diminishes when the number of wheels is increased.

10. That the danger increases when the angle formed by the working side of the flange and the plane of the wheel increases beyond that necessary to keep the rounded edge of the flange clear of the rail on the sharpest curve it has to run on.

11. That the danger is increased by enlarging the diameter of the leading wheels.

12. That the danger is increased by diminishing the projection of the flange.

13. That the danger is increased by making the springs of the leading wheels more flexible.

14. That the danger is considerably diminished by lubricating the flanges of the leading wheels; and increased by applying sand to these wheels.

15. That, when the center of gravity is behind the driving axle, the danger is increased by an excess of super-elevation of the outer rail beyond that required to counteract the centrifugal force.

16. That the danger may be increased by shutting off steam and reducing speed while running on a curve.

17. That, although one engine or carriage may run round a curve with less tractional resistance than another, it is not therefore necessarily in less danger of leaving the rails. In many cases it is quite the reverse.

Lastly. That, assuming an adhesion of 40 per cent. of the weight to be possible, some engines of not unusual proportions have, as regards leaving the rails, a very narrow margin of safety: so narrow that, in any other matter connected with the running of a train, a similar margin of safety would be considered insufficient.

## Appendix I.

The paper was suggested by an unintentional experiment, in which the springs of the driving wheels of a six-wheeled engine were tightened to increase the available adhesion. This was overdone, and when the engine was pushed slowly along to remove it to another line of rails, the leading-wheel flange, on coming to a curve, mounted the rail. The springs were then slackened back to their old bearings, and the engine ran safely afterwards, as it had done before. The rails were dry, and owing to the nature of the ground they were in places sprinkled with sand, so that probably the adhesion was great in proportion to the weight.

This incident seemed not only to point to the recognized necessity of having a considerable portion of the weight of a six-wheeled engine resting on the leading wheels, or rather the outer one of them, to guide the other wheels around a curve, but also to suggest that it would be desirable to ascertain the limit of safety in this respect, as it appeared possible that, in practice, this limit is sometimes exceeded, and may account for many hitherto unexplained accidents.

The most satisfactory way of ascertaining this limit of safety would be by direct experiment; but an exhaustive series of such experiments would be an undertaking which would require the resources of a railway company.

In the absence of such experiments, and to afford an opportunity for preliminary discussion, it may therefore be advisable to attempt to estimate this limit of safety by inferences from experiments made for other purposes, and from the experience of accidents recorded in the Board of Trade Returns.

The subject is not devoid of public interest, as, according to the Board of Trade Returns of Railway Accidents in 1880, the deaths of passengers resulting from "passenger trains, or parts of passenger trains, leaving the rails," were more numerous than those from any other class of accident enumerated in the summary at p. 3.

## Appendix II.

A single narrow wheel rolling freely on a level surface at low speed runs in a straight line; but it is turned out of that line so as to run in a curve by an extremely small force; and, when the axis is kept in the direction of a radius to any curve, the wheel traverses that curve with very little resistance. Two wheels of the same size, keyed fast on the ends of the same axle, roll, upon a flat surface, in a straight line at right angles to their axis; and they cannot be turned out of that line without causing one wheel to slide backwards or forwards. When only the outer one of two such wheels is guided around a curve by a rail the inner wheel outruns the outer until the axle becomes parallel with the rail, or at such angle that the wheels cease to revolve. To enable two wheels on the same axle to run around a curve without sliding, it is necessary to make one of them larger than the other, or to make one or both of them loose on the axle.

Two wheels, mounted one in front of the other (as in a bicycle), on parallel axles, also roll in a straight line at right angles to their axes, and any deviation from this straight line can only be accomplished by causing one wheel to slide sideways. If two such wheels on parallel axles are caused to run in a curve by a rail or guide acting on the front wheel, that wheel on first entering the curve

slides sideways in an inward direction toward the center of the curve, but still with a direction giving it a tendency to run outwards. The hind wheel by this motion is turned inwards, until the axis assumes a radial direction, when it follows the front wheel, though not exactly in the same track, being nearer to the center of the circle. This seems to be the only combination of equal and parallel wheels in which, the front wheel being guided in a curve, the other or others take up a definite relative position, whether they are loaded equally or unequally. In all other combinations, the positions of the wheels depend upon their loads and the state of the surfaces as regards friction, owing to the sometimes conflicting tendencies of all the wheels, except the front ones, to run with their axles radial, and of all the inner wheels to outrun the corresponding outer ones.

To allow two wheels, one in front of the other, to travel around a curve without slipping, the axles must be made to converge towards the center of that curve. When three wheels, on the same plane, are mounted on parallel axles, and the front wheel is caused to move in a circle, the middle and hind wheels have each a tendency to run with its axis in a radial direction; but as it is impossible that they can both do this, they take up positions such that their plane forms a tangent to the curve, either at the more heavily loaded of the two wheels, or at a point somewhere between them, nearer to the more heavily loaded wheel. Thus a carriage on four or more equal wheels, fixed on two or more parallel axles, will, on a plane surface, run in a straight line, and can only be turned out of that line by at least two of the wheels being made to slide backwards and forwards, and at least two to slide sideways, one of which is at the same time sliding backwards or forwards; so that at least three wheels (or rather all the wheels but one) must be sliding.

As stated in a former discussion, "A model carriage, having two pairs of wheels fixed on parallel axles, the diameter of the wheels on one side of the carriage being less than those on the other side—this model carriage being placed on a board, and one end of the board lifted until gravity caused the carriage to run down—it was found that the carriage ran straight, and not, as might have been expected, in a curve." This, however, is the case only when the carriage has a comparatively long wheel-base. When the wheel-base is less than the width between the wheels, the carriage travels in a curve. The shorter the wheel-base, the more nearly does the curve seem to approach that proper to the cone formed by a pair of wheels, and the carriage turns in this direction even although the wheel-base is longer on the side next the small wheels than on the other side. The model thus seems to travel in the direction which causes the smallest amount of sliding, whether this sliding takes place in the direction of the planes of the wheels, or of their axes; that is to say, along or across the rails. Therefore, in a carriage or engine with a long wheel-base, it would be a greater advantage to have the axles radiate than the wheels to run loose on the axles; while, with a broad gauge and a very short wheel-base, it would be better to have loose wheels than radiating axles. This is more evident if the proportions of wheel-base and gauge are carried to their extreme limits.

Suppose the wheel-base of a four-wheeled carriage to be the longest possible, namely nearly equal to twice the radius of the curve on which it runs, and the gauge to be very narrow, then, if the axles are parallel, the wheels will be nearly at right angles to the rails, and will not roll, their whole motion being sliding sideways; while, if the axles are radial, the wheels on each, though of the same size, being close together, will roll around the curve without much friction.

Suppose the gauge to be the widest possible, namely nearly equal to the radius of the curve, and the wheel-base extremely short, then the axles will be so nearly radial, that the wheels will roll around the curve with very little sliding in the direction of their axes, or across the rails; but if they are all of one size, to enable them to run without an excessive amount of sliding in the direction of the rails, they would require to be made loose on their axles, since the inner wheels, being close to the center of the curve, have hardly any distance to travel, and so hardly need revolve.

When a carriage or engine with four equals on two parallel axles is running on

a curve at slow speed (or at such speed that the cant of the rails balances the centrifugal force), the carriage not being attached to a train, and there being no play between the flanges of the wheels and the rails, then both axles are parallel to a radius half-way between them, and none of the wheels are parallel with the rails on which they run, the leading wheels standing across the rail in a direction giving them a tendency to run outwards, and the trailing wheels at an equal angle in the opposite direction, with a tendency to run inwards. Suppose, now, the flanges were removed from all the wheels, the carriage would run straight forwards at a tangent to the curve, and the path traced by the rail on the circumference of each wheel would, for a short distance, be a helix or screw, with an obliquity or pitch corresponding with the angle formed by the wheel and rail. If the helix is right hand in the case of the leading wheels, it will be left hand in that of the trailing wheels. The wheels, however, being prevented by their flanges from running straight on, slide across the rails to the extent of the pitch of the helix during each revolution, the leading wheels sliding inwards towards the center of the curve, and the trailing wheels outwards. The flange of the outer leading wheel is thus forced against the rail by a pressure sufficient to cause both the leading wheels to slide inwards across the rails; and the flange of the inner trailing wheel is acted on by a pressure sufficient to cause both trailing wheels to slide outwards across the rails.

Owing to the difference of the lengths of the inner and outer rails, either the wheels on the inner rail, besides sliding across the rail, will also slide backwards, or those on the outer rail forwards. The former is probably the case in ordinary working, when an engine with all wheels coupled is dragging a load, and the latter when running by momentum or down an incline with steam shut off. For the present purpose, however, it is only necessary to consider which will be the case when the flange of the outer leading wheel is in the act of mounting the rail. At that time, the whole of the load on that wheel is borne by the adhesion of its flange, and the tread is relieved of all load and adhesion, so that the wheel is running on a diameter larger than that of the tread, and larger, on almost any curve, to a sufficient extent to allow the inner wheel to revolve at the speed due to its tread, running on the shorter length of the inner rail. If all the wheels are coupled, the inner trailing wheel also revolves at the speed due to its tread, leaving the outer trailing wheel revolving at a speed slower than that due to its tread, running on the greater length of the outer rail. In this case it is probable that this one wheel slides forward on the rail, the whole of the wheels thus revolving at the speed due to their treads, traveling over the length of the inner rail.

The outer leading wheel thus slides forwards, and at the same time inwards across the rail; the inner leading wheel slides only inwards across the rail; the outer trailing wheel slides forwards and outwards across the rail; the inner trailing wheel slides only outwards across the rail. The sliding motions of the wheels are thus similar to those which would take place if the engine, without moving forwards, revolved horizontally about a center situated half way between the two inner wheels; and the distance which any wheel slides along and across the rail while the engine makes a complete revolution, is the same, or nearly the same, as that which it slides while the engine is running around a complete circle of any diameter, however large. Thus the energy expended in overcoming the friction of the treads of the wheels in going around a circle is a constant quantity, whatever may be the size of that circle. From this it follows that, as generally admitted, the additional tractional resistance due to that friction varies inversely as the radius of the curve; but it does not follow that the tendency to leave the rails increases in anything like this ratio.

When, by the force of traction, the inner wheels are caused to slide backwards, the sliding motions of the wheels will take place around a point situated between the two outer instead of the inner wheels.

Again, when the clearance between the flanges of the wheels and the rails is sufficient, the trailing axle runs forwards until it assumes nearly the direction of a radius to the curve. It may be slightly in advance of this position, or slightly

behind it, the precise position depending upon the comparative loads on the wheels. and the proportion of wheel-base to gauge. In this case, supposing as before that the outer wheels slide forwards, the outer leading wheel slides inwards across the rail and at the same time forwards; the inner leading wheel slides only inwards across the rail; the outer trailing wheel slides only forwards; and the inner trailing wheel does not slide at all. The sliding motions of the wheels on the rails are thus nearly the same as those which would take place if the engine revolved about the inner trailing wheel. The flange of the inner trailing wheel is thus relieved of all side pressure, and the only flange pressing against the rail is that of the outer leading wheel, which must thus exert the whole of the side pressure required to cause the sliding of its own wheel, of the inner leading wheel, and of the outer trailing wheel. The leading wheels now run at a greater angle with the rails than they did when the gauge was tight; and the distance which the wheels slide in going around a circle is greater.

A carriage with four, six, or more wheels on parallel axles, does not absolutely require flanges on any except the leading wheels, which being thus guided, the other wheels will follow them, and, if wide enough, will keep on the rails.

Thus, when there is clearance enough, or the curve is easy, the whole of the flange friction comes on the outer leading wheel.

## Appendix III.

In the case of a six-wheeled engine running, without exerting tractive force, with the inner driving-wheel flange in contact with the rail, it is even more probable than in the case of a four-wheeled engine, that the outer wheels slide forwards, and that the inner ones do not slide backwards. Assuming the wheels to be nearly equally loaded, the weight upon the driving wheels is not sufficient to enable their adhesion to cause them to form a fulcrum to move the trailing wheels across the rails. Thus, the inner driving-wheel flange is pressed against the rail, causing additional adhesion, to overcome which, in the event of the inner driving wheel sliding backwards, an additional pressure would be exerted by the flange of the outer leading wheel. This, in turn, causes an additional pressure on the inner driving-wheel flange, so that the two wheels act and react upon each other, and the side pressure on the inner driving-wheel flange causes the adhesion of that wheel to be greater than that of the outer one.

## Appendix IV.

With a tire having a flat or conical flange sharply joined to a cylindrical or slightly conical tread, or with almost any tire running on a rail considerably rounded on the top, there are two points of contact, one between the top of the rail and the tread vertically under the wheel's axis, and the other between the side of the rail and the flange some distance in advance of the axis when running towards the rail on a curve.

With a tire whose flange is joined to the tread by a curve of considerably greater radius than that of the rounded corner of the rail, or with almost any tire running on a flat-topped rail, the two points of contact merge into one when the wheel is running towards the rail on any ordinary curve, the wheel resting on the rounded corner of the rail at some point determined by the proportion of weight to side pressure, and this point is slightly in advance of a perpendicular from the wheel's axis. In this latter case flange-friction can hardly be said to have a separate existence.

## Appendix V.

Had the engine been exerting a considerable amount of tractive force, the case would have been altered, perhaps, somewhat as follows: The tractive force being, as regards the adhesion of the wheels, equivalent to a strain pulling the wheels backwards, the inner driving and trailing wheels would slide backwards, instead of the outer ones forwards. The backward pull would therefore relieve the outer leading wheel of the side pressure required to effect the longitudinal sliding motion, leaving only that required to effect the cross sliding. This pressure would thus be reduced:

| | |
|---|---|
| For the outer leading wheel 0.0(4.05×7.16=29=N) | =0.0 |
| For the inner leading wheel 0.2(3.5 ×7.16=25.060) | ÷7.16=0.70 |
| For the outer driving wheel | =0.0 |
| For the inner driving wheel | =0.0 |
| For the outer trailing wheel 0.2(3.75×7.16) | ÷7.16=0.75 |
| For the inner trailing wheel 0.2(4.0 ×7.16) | ÷7.16=0.80 |
| | Tons 2.25 |

Assuming, however, that the drag-link was attached to the engine at a considerable distance behind the driving axle, then the backward pull would give this part of the train a tendency to straighten out, and so increase the side pressure on the outer leading wheel. Assuming the backward pull to be equal to one-fifth of the weight of the engine, or $\frac{25.65}{5} = 5.13$ tons, acting at 11 feet behind the driving axle, where the coupling would form an angle of about 179° with the center line of the engine, it would cause an inward pressure at the coupling of 5.13×sin. 179°=0.089 ton, which, supposing the engine to be revolving about either driving wheel, would cause an additional outward pressure on the outer leading-wheel flange of $\frac{0.089 \times 11 \text{ feet}}{7.16 \text{ feet}} = 0.14$ ton, which, added to 2.25 tons brings up the pressure to only 2.39 tons. Thus the side pressure on the outer leading-wheel flange is considerably less when an engine is exerting its tractive force, than when running with steam shut off.

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# THE SUEZ CANAL—ITS ENGINEERING, COMMERCIAL, AND POLITICAL ASPECTS.

By Lieut.-Gen. F. H. RUNDALL, C.S.I., R.E., late Inspector-General to the Government of India.

From the "Journal of the Society of Arts."

The Suez Canal has of late occupied, and is still occupying largely, the attention of all Europe—and, perhaps it may not be too much to say, of the whole civilized world. At the same time notwithstanding so much has been written and talked of about it, beyond the fact of its being the great thoroughfare to India for the ships of all the Western nations, but little comparatively regarding it is known to the public generally.

The mercantile world, and those more particularly interested in the Canal, can of course obtain from the Parliamentary Blue-books a mass of important information and statistics not otherwise available, more especially as regards the official negotiations which have passed between the various Governments in reference to the commercial and political aspects of the undertaking. But Blue-books are not attractive reading, even to those who have leisure, while business men seldom have time sufficient to devote to their study. The Society of Arts, therefore, being desirous of procuring a succinct, and at the same time correct and comprehensive, account of the Suez Canal in all its aspects, an endeavor is made, in the following remarks, to meet that desire, by collating, from official and other publications, the most important of the particulars available, and, at the same time, to consider the various bearings of a question which is now attracting such universal attention, and which is generally felt to be of primary importance to England at the present time.

The Suez Canal has to be viewed in three aspects:

1. As an engineering work.
2. As a commercial undertaking.
3. As a political problem.

Before commencing to discuss these three points in detail, I propose to give a short history of the scheme, from the period of its first incubation, to its present stage of development.

The first idea, in modern times, of connecting the Mediterranean with the Red sea seems to have originated with Napoleon I., but before he could give any practical shape to that idea, the Emperor had to evacuate Egypt.

Nothing further was attempted till the year 1842, when Captain James Vetch, of

the Royal Engineers, published a pamphlet, in which he indicated the direction a canal should take across the Isthmus, and its vast importance to this country; but the Government of the day were opposed to the construction of any canal, and Captain Vetch's suggestions fell to the ground. Subsequently, in the year 1846, a Commission of engineers assembled to discuss certain proposals, which, however—beyond exposing the error as to a difference of level of thirty feet between the Mediterranean and Red Sea—came to nothing, and so the subject dropped until 1854, when it was revived by Monsieur de Lesseps putting forward his project for a direct canal between the two seas. His proposals met with considerable opposition in England, strangely enough from commercial authorities, who foresaw the total revolution that would be made in the carrying trade, but who were apparently unable to appreciate or believe in the enormous advantage that would accrue to them from such a revolution. But there was likewise a formidable political opposition, based on certain objections which the Government of the day foresaw would, unless duly safeguarded, be likely to give rise to considerable difficulties in the future. That those objections were not destitute of foundation, every statesman of the present day will readily admit; and the difficulties which are now attendant on current negotiations only too plainly indicate that a scheme which at first apparently concerned only a small body of speculators, has turned out to be a political problem, perplexing more or less the whole continent of Europe; but the difficult task of solving which has, by a general consensus of opinion, devolved, and rightly so, upon England.

This phenomenon is not without its prototype. Our Eastern Empire, as is well known, had its first beginnings in the ventures of a few enterprising merchants, whose marvelous prosperity, in spite of themselves, raised the East India Company to the highest importance as a political factor, stimulated its acquisitive energy until its operations got beyond control, and the Merchant-princes of the East found themselves overturned in the great convulsion which, in 1857, shook the Empire to its foundations, and so nearly involved the whole of the gigantic fabric in ruins. It is, to say the least, a curious coincidence that, ere India had recovered from the throes of that convulsion, an enterprise like the Suez Canal, originated by private speculators, and the interests and prosperity of which are so closely dependent on those of India, should be started into existence, and, after nearly foundering, should, in a brief time, enter on such a career of prosperity, become a link between gigantic interests, and in its turn rise to be an important factor in the political world; and what is stranger still, instead of proving, as was anticipated, a spear for piercing its armor, it has been converted into the first line of defence for England—a veritable covered way for safe-guarding its Eastern possessions! Is the parallel to be pursued any further? Doubtless the projector would exclaim, "*Dii omen avertant!*"

But to return to the history. In 1859, Monsieur de Lesseps' scheme was actually begun, and after successfully combating many difficulties, both physical and political, the Canal, though incomplete, was finally opened from sea to sea ten years afterwards, in the year 1869, with great pomp and ceremony, in the presence of a brilliant Imperial assemblage. From 1869, to the present time, the Canal has been in constant use, without a day's intermission. Its career has not been altogether unchequered; but it has emerged from its difficulties, and has now reached a pitch of prosperity exceeding the most sanguine expectations of its projector.

To pass on to the consideration of the Canal as an engineering work. It is unnecessary, as well as out of place here, to enter into minute details of construction, and therefore only its most general features will be brought under review. There is little room to doubt but that the engineers who were entrusted with the surveys, selected, on the whole, the most favorable line for the Canal, as regards economy of first construction. The entrance from the Mediterranean is between two long piers, or moles, run out from the coast, with the idea partly of creating a species of harbor, in which vessels approaching the Canal might lie in quiet water. The western mole, however, was also intended to serve as a protection against the entrance becoming silted by

the Nile deposit, which is transported during the floods of that river in enormous quantities along the coast for many miles.

It may be open to comment whether, instead of placing the entrance from the Mediterranean at Port Said, it might not have been better made more to the eastward, and further removed from the influence of the silt-laden waters of the Nile. It is said that the difficulties connected with the silt deposit at that entrance have been overcome, but that assertion must be received with caution; for it is quite certain that the coast line between the Damietta mouth and near the Canal has advanced considerably, while the 5-fathom line had receded, as noticed in Sir John Stoke's Report in 1874, 1,200 yards in three years. The diagram on the wall is on too small a scale to show the present position of that line, and the rate at which the intervening space is being filled up, or how far the statements of Monsieur Lemasson, the French engineer, are borne out, as to the effect that a deposit of 7½ million cubic meters per annum was likely to produce. The western mole has, it is believed, now reached a length of nearly 3,000 yards, and to where the 5-fathom line used to lie. Of course, as deeper water is reached, the process of silting up will become slower, but that it cannot be wholly arrested by mere extensions of the western pier, though accompanied by dredging, is incontrovertible. Hence it may be admitted that the further the entrance could have been removed to the eastward, the less inconvenience would have been experienced from the translation of the Nile deposits.

With the exception of some unnecessary curves, especially that near the town of Ismailia, the general alignment of the Canal is satisfactory; but since the traffic began to increase, the mistake of making those curves has become apparent. It must be admitted, however, that the mistake has been aggravated rather by the continually increasing length given to vessels which have been (and are still being) built for the navigation of the Canal.

The total length of the line from Port Said to Suez measures 88 geographical, or 100 land miles, of which 39 miles only are in cuttings through land, the other 61 miles running through a succession of lakes. The northern half of the Canal, as far as Lake Timsah, had to be excavated by manual labor, until sufficient depth could be obtained to admit of dredging operations; but the portion south of Lake Timsah was excavated entirely by dredgers, as water was obtained on a high level from the Freshwater Canal, which had, meanwhile, been constructed; and thus by filling up the line of the Suez Canal to that level, sufficient depth was obtained for floating the dredgers. At El Guisr, Serapeum, and the Chalouf plateaux—in all, about eighteen miles of cutting—rock (more or less hard) was encountered, rendering excavation both difficult and costly, as blasting operations had to be resorted to. Though along the rest of the line the material to be excavated consisted principally of sand, with an occasional admixture of clay, yet the task of not only excavating soil to a depth of 26 feet below water, but of conveying it away, involved some difficulty, which was finally overcome by some very ingenious adjuncts and appliances to the ordinary dredgers. The excavated material could not, as in the case of river or harbor dredging, be simply lifted into hopper barges, and be towed out and discharged into the sea; it had to be deposited on banks on either side, the height and breadth of which were, of course, continually increasing.

According to Lieut.-Colonel (now Sir A.) Clarke's report, written in February, 1870, it was originally intended to construct the Canal with a surface width of 325 feet, and a bottom width of 144 feet; but the latter, at the present time, does not average more than 70 feet. The side slopes, which vary according to the soil passed through, are being now faced with stone, by which means a considerable length of the Canal is protected from the erosion which used to take place from the wash of the steamers.

A minimum depth of 26 feet is maintained throughout the Canal. The bottom width being only half that originally intended is, of course, insufficient to allow of vessels passing one another, and obliges a low speed to be maintained.

Sir John Stokes observes, in a report dated April 20, 1876, that, in his opinion, the narrow width is not altogether a disadvantage, inasmuch as by necessitating the Canal being worked on the block sys-

tem the risk of collision is greatly reduced, and the passage of vessels is, in the long run, performed in a shorter space of time than if vessels were allowed to navigate independently. Unquestionably, the risk of collision is especially to be avoided where large vessels are concerned, for the momentum of masses 2,000 to 4,000 tons in weight, moving even at a low velocity, is exceedingly great, and when brought into collision must be attended by disastrous results. But the narrowness of the section operates disadvantageously in retarding the speed of vessels below the economical unit. When the difference between the sectional area of the Canal and that of the vessel's midship section is so small, the piling of the water caused by the vessel's displacement is greatly increased; the friction on the sides of the vessel, as well as on those of the Canal, so retards the flow of the water that the void created by the vessel's onward movement cannot be filled sufficiently fast, and hence the steering power is destroyed, and the ship either takes the ground astern or runs bow on to the bank.

By experiment on the Indian Canals, it was found that when the relative sectional area of the vessel and canal were in the proportion of from 1 to 12 or 14, with a depth of 3 to 4 feet under the steamer's keel, there was no perceptible piling, and a speed of from 8 to 10 miles an hour could be maintained, but wherever that relative proportion fell short, piling began to take place, and the speed was proportionately diminished. If, therefore, the Suez Canal were finished more nearly to its original dimensions, or say, to 320 on the water line, and 200 at the base, with slopes of 2 to 1, it would, if 30 feet deep, contain a sectional area of 7,800 square feet, and yield a proportion of 13 to 1 to all vessels whose midship section did not exceed 600 square feet, and which would probably include all ships registering 2,000 tons. The block system, if found absolutely necessary, might still be maintained, but it would give the opportunity for such vessels to accomplish the passage of the Canal in twelve hours of daylight. The narrowness of the bottom width of the Canal not admitting of large vessels passing one another, side-cuttings, called "Gares" or stations, have been made at intervals of five miles, wherein large vessels can lie moored during the night, or whenever the necessity may arise. As observed before, the method of working the Canal is that known on railways as the block system, no vessel being allowed to proceed from one station to another until the line is signaled clear, for which purpose a perfect telegraphic communication is kept up through its entire length. The arrangements for carrying this out are described in Sir J. Stoke's report, as follows:

"Each of the superintendents of the transit at Ismailia, Suez, and Port Said has a model of the canal in his office, with miniature vessels, which enable him to fix the position of each ship as it passes through. As soon as a vessel enters the canal, either at Suez or Port Said, its counterpart is launched on the models with name affixed. As it passes each siding, which is also a telegraph station, its position is made known to the superintendents, who fix its place on the model, and the chief transmits orders for the guidance of the pilot on board. Then, whenever a vessel approaches a siding, it finds a signal directing its movements, whether it is to remain or move; if to remain, the orders are strict that it is to make fast to the bank in the siding, and to leave the navigable channel quite free."

If these orders are acted up to, it is impossible for two vessels to meet in the section between two sidings, and so collision is rendered impossible. The canal is also furnished with every accessory in the shape of light-houses, beacons, buoys, telegraphs, &c., for facilitating the navigation as far as possible.

It would have been impossible to carry on the work of the Maritime Canal without a supply of fresh water, which was wanting along the whole line. The company was therefore empowered by the Egyptian Government to construct a canal for irrigation and navigation from the River Nile, at a point below Cairo to Timsah, and thence to furnish a supply for the towns of Port Said and Suez. This canal has since been enlarged and completed with locks, and is the work which proved of such invaluable aid in the late military operations in Egypt. The extensive tract of land granted to the company, and for which irrigation

had to be supplied, was subsequently taken back by the Government, and the company empowered only to use the water for domestic purposes.

So far, then, as an engineering work, it would leave little to be desired, had vessels of the type in vogue before its construction continued to be used. But as the science of shipbuilding progressed, it has been found possible and necessary, in order to keep up with the requirements of trade, to construct vessels of much larger dimensions, and on different lines; and, consequently, ships have outgrown the existing dimensions of the canal, and demand increased accommodation. It has been seen that the original intention was to construct the canal of double the present dimensions, but the financial necessities of the company prevented them from carrying out that intention. Though forced upon them, the course adopted was quite the right one; for the canal, on the smaller scale, has thoroughly served its purpose for thirteen years; and now that it is placed in a highly satisfactory and flourishing financial condition, the time has arrived when additional capital may prudently be laid out, to increase the accommodation which a rapidly-increasing trade demands. The best means of providing additional accommodation is still a matter under consideration, notwithstanding certain measures have been publicly announced in some of the daily papers as having been definitely settled. Probably the company, finding that it will be to their own interest not to postpone any longer meeting the demands made upon them, have decided on carrying out meanwhile certain obvious improvements; but the larger and more permanent provision, that must sooner or later be made, has yet to be settled. The possible alternatives that present themselves will be explained hereafter. Meanwhile, there only remains to be noticed, under this head, the items of cost of original construction, repairs and supervision. The total capital expenditure up to 1869, the year in which it was opened, amounted to £18,000,000. The sum spent annually on repairs and improvements carried out from revenue, does not vary very much, amounting, in 1880, inclusive of supervision, to £218,900; and, in 1881, to £212,490, thus averaging less than 1¼ per cent. on the first cost—a very moderate and satisfactory outlay.

Passing on now to consider the canal in its second aspect, as a commercial undertaking, there is much of a very interesting character to be explained. The first fact is one which, outside official circles, will probably be entirely new to 99 persons out of 100, and that is that La Compagnie Universelle du Canal Maritime de Suez (The Universal Suez Maritime Canal Company) is not a French but an Egyptian company, having its principal office at Alexandria, amenable to the laws and customs of not the French, but of the Turkish Empire, and, therefore, subject to the jurisdiction of its local tribunals. The importance of this fact will be sufficiently evident, when the disputes which subsequently arose between the directors of the company and the Egyptian and Turkish Government come to be noticed. It is not too much to add that, but for this precaution at the time of the formation of the company, it would not only have been impossible for the nations of Europe to make use of the canal, but that the subsequent attempted exactions of the company might have led to very serious misunderstandings, if not to actual embroilments, amongst some of the European Powers. Before proceeding, however, to explain the more especial commercial features of the canal, it is necessary to draw attention to the nature and terms of the various "concessions" granted by the Egyptian Government, and subsequently ratified in a firman by the Sultan as suzerain. Eight concessions were granted by the Viceroy of Egypt between the years 1854 and 1869, the details of which have been published in the Parliamentary Paper, "Egypt, No. 6 (1876)." In the first of these, dated November 30th, 1854, the Viceroy confers on Monsieur de Lesseps "exclusive power to form and direct a universal company for piercing the Isthmus of Suez, and the working of a canal between the two seas within, and subject to certain specified restrictions and conditions," the most important of which, as regards the constitution of the company, were:

1. That the director of the company was to be always named by the Egyptian

Government, chosen, as far as possible, from amongst the shareholders most interested in the undertaking.

2. That the duration of the concession was to be for 99 years from the date of the opening of the canal throughout.

3. That the Government reserved to itself the power to erect any fortifications it pleased in the neighborhood.

4. That the Egyptian Government were to receive, yearly, 15 per cent. of the net profits shown in the balance-sheet of the company, without prejudice to any dividends belonging to the shares which the Government reserves a right to take on its own account, and without any guarantee on its part.

6. That the rest of the profits were to be divided as follows: 75 per cent. for the benefit of the company; 10 per cent. for the benefit of the original promoters.

7. That, on the expiration of the concession, the Government to succeed to the company, enjoy all its rights, and enter into full possession of the canal.

8. That no alterations could be made in the statutes of the company without receiving the previous approbation of the Viceroy.

The second concession, dated 5th January, 1856, is an amplification of the first one, explaining, in more detail, the nature of the charges and concessions, the most important of which are:

1. The limitation of the power of the company to carry out a canal east of the Nile, from the Gulf of Pelusium, and authorizing the construction of a fresh-water canal from Cairo to Lake Timsah.

2. The solemn declaration of the Viceroy, subject to ratification by the Sultan, of the Maritime Canal and its ports being always open as neutral passages for all merchant ships on payment of dues, without preference to any vessel, company, or person.

3. The dues on vessels navigating the canal not to exceed 10 francs per ton of capacity and per head of passengers.

This concession was made over to Monsieur de Lesseps, previous to ratification by the Sultan, to enable him to constitute the financial company. Amongst the statutes of the company approved by this concession was one appointing its seat at Alexandria, and its administrative domicile at Paris.

The statutes direct that the annual proceeds were to be applied in the following order:

1. To expenses of maintenance, working and administrative, and generally all charges of the society.

2. To interest and sinking fund of such loans as might be contracted.

3. Five per cent. on capital of society to be applied to provide for shares redeemed and not redeemed, and an annual interest of 25 francs per share; the interest attributable to shares redeemed being carried to the sinking fund.

4. Four hundredths per cent. on the capital to be applied to the sinking fund.

5. To the amount required for creating and keeping up a reserve fund for unforeseen expenses. The excess over the above proceeds to constitute the net profits, which were to be distributed as already stated.

Concession No. 3, dated 6th of August, 1860, is a financial agreement containing the first settlement of accounts with the Egyptian Government respecting its subscription; and, in March, 1863, concession No. 4 contained another financial agreement for settling the balance payable on shares subscribed for by the Egyptian Government.

At this period intervenes an important act by the Porte, which perceiving in the concession of the fresh-water canal, and of vast tracts of land, a menace to its independence, and in the stipulations for the providing of workmen, a violation of the laws under which the Ottoman Empire is governed, declared by a diplomatic note, dated 6th April, 1863, addressed to its representatives in Paris and London, its opposition to the continuance of the works. The same notification was made to the Viceroy, who communicated it to Monsieur de Lesseps, expressing his intention to treat on and settle these questions with the company, and accrediting Nubar Pasha to come to an understanding on the proposals to be submitted. The Council of Administration rejected the proposals, and then the Khedive begged the intervention of the Emperor of the French, who, after receipt of the report of the Commission which he appointed to examine into the questions involved, gave his decision; awarding to the company a sum of 84 millions of francs, or £3,360,000, the payment of which was to be spread over

a period of fifteen years, ending with 1st of November, 1879.

Consequent on this award, a sixth convention was drawn up, dated 30th January, 1866, in which the following important articles occur:

1. Egyptian Government to keep all strategical points.

2. Power for the Government to occupy sites for post-offices, customs, barracks, and other services.

4 and 5. The Government to take possession of the fresh-water canal, on the terms specified.

A further agreement was drawn up in the following February, and received the sanction of the Sultan in a firman, dated 19th March, 1866, which stated the conditions to which such a sanction was subjected. One important article being to the effect:

"That the Maritime Canal and its appurtenances remain subjected to the Egyptian police, which shall exercise its functions freely, as at every other point of the territory, so as to secure good order, the public peace, and the execution of the laws and regulations of the country."

In Article 16 occur the words: "The Universal Company of the Maritime Canal of Suez, being Egyptian, it is governed by the laws and usages of the country;" and the articles which follow declare its complete subjection to the Egyptian Government. Two agreements, dated 23d April and 26th January, 1869, complete the negotiations prior to the opening of the canal, and in them is the arrangement by which the Viceroy assigns fifty coupons from each of the 176,662 shares belonging to the Egyptian Government, for the space of twenty-five years, in settlement of the 30,000,000 francs, the value awarded for the resumption of the fresh-water canal from the company.

The recapitulation of the concessions though somewhat tedious, is essential to the right understanding of certain events which occurred shortly after the opening of the canal, as also of the obligations that regulated the amount of dividends which the company paid to the shareholders, as well as of the status of the company generally.

Turning now to the cost of the canal, already stated to be £18,000,000, it appears that of this, the amount of capital originally subscribed was only £8,000,000, in 400,000 shares of £20 each. That amount was subsequently augmented by the loan of 1867 for £4,000,000, being debentures ("obligations") redeemable in fifty years, bearing 5 per cent. interest, and having a first charge on the profits. After these, the loans of 1871 were contracted by the issue of thirty years bonds, bearing 6.7 per cent. interest, which, in their turn, were succeeded by £1,360.000, representing consolidated arrears of interest on ordinary shares, in the shape of seven coupons of 5 per cent. yearly. Lastly, came the advance on detached coupons of the Egyptian Government shares amounting to £1,200,000, styled "delegations," and entitled, for twenty-five years, to 5 per cent., and a dividend (if any) on those shares. The balance of the cost of the canal was made up from the indemnities which had been paid by the Khedive under the late Emperor's award. In 1870, the year after the opening of the canal, the prospects of the company being doubtful, a suggestion was made by the Khedive that it should be transferred to some English company.

The negotiations which followed this suggestion belong rather to the political than the commercial aspect of the canal, and will be better adverted to hereafter.

The doubtful prospects of the company, however, led to a very objectionable proceeding on the part of the Board of Administration, viz., in determining arbitrarily the interpretation of the term, "ton of capacity," on which the authorized due of ten francs was leviable. That due had been for the past three years, levied on the net register tonnage, as shown in the ship's papers, and calculated on the Moorsom system, which, after reckoning the gross tonnage of the ship, deducted the space occupied by the engines, fuel, &c. The term, "ton of capacity," not having, however, been actually defined at the outset, the company took upon themselves to interpret that term as signifying the "real capacity" of the ship, which, by a commission of their own appointment, they declared to be greatly in excess of the net register tonnage, the result being that the dues were levied on the gross tonnage, and consequently the tolls payable by every

ship traversing the canal were raised 30 per cent. The burden of such an interpretation at once made itself felt in the case of steamers, in which the machinery occupies one-third of the tonnage, and was therefore equivalent to levying 50 per cent. more from steamers than had been levied in the three previous years. Remonstrances were immediately put forward by the principal maritime companies in England, and the Messageries Nationales actually brought an action against the Canal Company in France. A decree was first given in their favor, but it was afterwards reversed on appeal.

The protest, however, by the British Government led to the assembly of an International Commission at Constantinople, and to the adoption of a style of measurement according to what are known as the Constantinople Rules. It was not, however, without great discussion, in which the tact and firmness of the English delegates, Sir John Stokes and Sir P. Francis, were eminently conspicuous, that the proceeding of the Canal Company were set aside, and the Moorsom system of measurement declared to be correct, and adopted accordingly.

Finding themselves entirely in the minority, the French delegates eventually joined in signing the report of the Commission, which set forth the rule to be followed in the measurement of vessels, and the deductions to be made in order to arrive at the net tonnage. As a set-off, however, against the diminished revenue which it was supposed would follow the first introduction of the new rules, the Commission recommended permission being given to the company to levy temporarily a graduated surtax of 3 francs per ton on vessels provided with the prescribed certificate of net tonnage measurement, on condition that the deduction did not exceed 50 per cent.

Vessels not measured according to the Moorsom system were to have their tonnage reduced by calculation to the scale of the Danube, and to pay a surtax of 4 francs per ton, as also vessels measured according to Section A, Clause 23, of the British Merchant Shipping Act of 1854.

The surtax of 3 francs to be reduced in the following proportions: To 2½ francs per ton, as soon as the net tonnage passing through the canal reached 2,100,000; to 2 francs when it reached 2,200,000; and so on, ½ franc for each annual increase of 100,000 tons up to 2,600,000 tons, at which figure the surtax was to cease altogether, and the original due of 10 francs per ton only to be levied. Vessels of war, transports, and vessels in ballast to be exempt from the surtax.

The Porte was pleased to approve of the report of the Commission, and desired the Khedive to inform the company of the same, and direct it to be put in force in three months time.

Monsieur de Lesseps first protested, and then refused to accept the new rules; but, as in the event of his persisting in his refusal the canal was to be seized by the Egyptian Government, he submitted, but under a protest, which was not withdrawn till some years afterwards.

Towards the close of the following year a rumor got abroad that a project was on foot to purchase the shares of the Canal Company belonging to the Egyptian Government. This led to the correspondence which is given in detail in Parliamentary Paper, Egypt, No. 1 (1876), and which ended eventually in the purchase of those shares, 176,602 in number, for a sum of £4,000,000.

In 1876, after the purchase had been concluded, and in consequence of a new convention, the company withdrew all opposition, accepted all that had been laid down by the Constantinople Commission, and agreed to the decrease of the surtax at fixed dates, and to its total abolition in 1884, and consented to expend one million francs per annum for thirty years in improving the canal. That convention, which is known as the Stokes-Lesseps Convention, has consequently been in force up to the present time.

It is time, now, to turn to that part of the subject which possesses the greatest interest for the English public, and that is the traffic passing through the canal, and the revenue derived therefrom; for it indicates not only the relative importance of the canal to the several nationalities which make use of it, but it incontestably proves that were it not for the trade carried by British vessels, the Canal Company must, long ere this, have entirely collapsed, and were it now

to be withdrawn through any other channel, the Suez Canal could not possibly be maintained.

Seven years ago an interesting paper was read before the Society, by Mr. Charles Magniac, on the "Commercial Aspects of the Canal," in which, on the whole, he took rather a depressing view of the prospects of British trade at the time, saying: "That the returns up to that time showed that the great expectations entertained of a large increase of trade due to the canal, had not been borne out;" "that the imports into India were feebly stationary" "that the falling off from France was immense, but greatly due to the effects of war;" "that the item most deserving of attention was that of the Mediterranean ports."

Similarly, in regard to the exports, the United Kingdom told the same story of stagnation, and it was only the Mediterranean ports that showed a buoyant and increasing trade, and that principally in the staple articles of Indian produce. But he summed up his description with the words, "Whatever we may say or do, however much industries or individuals may suffer at first, one thing we do know, that India has been brought within three weeks journey of England. We gained our supremacy there when a letter and its reply were frequently 12 months on the road. The same thing can now be done in 12 minutes. Is it to be supposed that this energetic nation will not find its advantages in such facilities as these? I am sure it will, and that even many here will live to see it." Mr. Magniac has doubtless ere this already satisfied himself of the verification of his prediction; but as possibly many are present who have not had the same opportunity, I propose briefly to call attention to the figures in the several tabular statements of the trade of India with England and the world generally, obtained from published official records of the Indian Government.

First, in regard to the imports of the United Kingdom; these show a steady increase from 1874, when they stood somewhat over 29½ millions, to over 32 millions in 1879–80, with the exception of the previous year, when, in consequence of the depression caused by the famine, they fell just below 29 millions. In 1880–81 they rose to £41,300,000, or an increase of over 33 per cent. In the foreign trade, France increased from £362,400 to £705,600, and Italy from £334,000 to £576,000.

From the rest of Europe the import trade is insignificant. The export trade to the United Kingdom does not show a similar increase in value, owing to the great fall in prices, but an examination of the quantities exhibits a satisfactory progress, while the exports to the principal European countries is more marked as regards increase in value. France having risen from £3,134,000 to £6,500,000; Mediterranean ports—Italy, £1,400,000 to £2,781,000; Austria, 1,428,000 to £2,226,000.

In five of the most important staples, cotton, rice, seeds, tea and wheat, the progress in exports has been as follows:

| | 1876-77. | | 1880-81. | |
|---|---|---|---|---|
| | Quantity | Value | Quantity | Value. |
| | Cwt. | £. | Cwt. | £. |
| Cotton, raw. | 4,557,914 | 11,746,184 | 4,541,539 | 13,241,734 |
| Rice..... | 19,548,731 | 5,742,540 | 26,769,344 | 8,971,661 |
| Seeds..... | 9,582,865 | 5,319,124 | 10,229,109 | 6,345,209 |
| Tea..... | 27,784,124 | 2,607,425 | 46,413,510 | 3,054,240 |
| Wheat..... | 5,588,336 | 1,956,333 | 7,444,375 | 3,277,942 |

Of the quantity, 4,541,539 cwts. of cotton 3,818,557 cwts. were taken by Europe; that is, 2,019,612 cwts. by England, 633,891 cwts. by Italy, 605,954 cwts. by France, and 559,100 cwts. by Austria.

Of the total quantity, 26,769,344 cwts. of rice, about half, or 13,582,300 cwts., were conveyed to Europe; of which, England and Malta took all but 300,000 cwts.

Of 10,229,109 cwts. of seeds, 9,705,200 were brought to Europe, nearly 5,600,000 cwts. coming to England, and 3,256,180 cwts. going to France.

Of the 46½ million pounds of tea, only one million went to the Australian market, all the rest being brought to England. In 1879–80, the price of tea was ruinously low, and a collapse in that industry was imminent; but happily, the Australian market was partially opened, and gave just sufficient stimulus to prices to avert disaster.

In 1875, only 1¾ million cwts of wheat were shipped from India. In 1880–81, there were 7½ million cwts., of which

England took 4,800,000 cwts., 1⅓ million went to France, and 790,000 cwts. to the rest of Europe.

The proportion of the whole trade which came to and left India by the Suez Canal, during the last five years, has been as follows:

| | Whole Trade. | *Via* Suez Canal. | Per Cent. |
|---|---|---|---|
| 1876-77 ... | 113,920,539 | 60,243,259 | 52.88 |
| 1877-78.... | 126,252,968 | 68,380,719 | 54.16 |
| 1878-79.... | 109,777,084 | 53,398 875 | 48.64 |
| 1879-80 .. | 122,068,908 | 63,033,231 | 51.64 |
| 1880-81.... | 138,108,657 | 81,175,876 | 58.78 |

The imports from the United Kingdom into India constitute 82.08 per cent. of the whole, and 42.33 per cent. of the produce shipped from India. The import trade is thus practically monopolized by Great Britain, the reason being that the only articles which the people of India largely consume are English products, in which other nations have not at present the capacity of competing with her for the supply of foreign markets.

On the other hand, the reason of her taking a smaller proportion of the exports arises from some of the most valuable Indian produce being shipped to other countries—notably, opium to China and the Straits; indigo, hides, and seeds to France, Italy, and the United States.

From these figures, it will be readily gathered that the commercial interests of England have not suffered from the canal, but, on the contrary have been largely augmented, and that while India has benefited by the opening of additional markets in Europe, England has also gained largely, and still maintains, a virtual monopoly of the Indian market for the disposal of her own merchandise, the value of which, in 1880–81, amounted to over 41½ millions sterling.

Passing on to the general trade through the canal, a reference to the tabular statements will show that, first, as regards the total tonnage, the number of vessels which passed the canal in 1870 was 486, and the tonnage 435,911 tons. In 1879, the vessels numbered 1,477, and measured 3,236,942; that is, while the vessels had increased threefold, the gross tonnage increased more than sevenfold. In 1870, the vessels averaged 900 tons each; whereas, in 1879, the average size reached 2,180 tons. In 1877, however, the greatest number of vessels, viz., 1,663, passed through the canal, but they only measured 3,418,950 tons, giving for the average of each vessel 2,056 tons. During the same period, the receipts of the company increased from £256,000 to £1,214,-520. Great as that increase was, it is nothing compared to the increase within the last three years. In 1880, the vessels numbered 2,026, with a gross tonnage of 4,344,519 tons; and in 1881, the number rose to 2,727 vessels, measuring 5,414,-050 tons.

Now, as to the nationalities of the vessels indicated in Table II. In the decade, ending 1879, out of 12,454 vessels, no fewer than 9,154, or three-quarters, were British; conveying 17,555,500 tons out of the total quantity, 23,105,535 tons.

In like manner, out of the 2,026 vessels in 1880, 1,592 were British, measuring 3,446,431 tons, out of a total of 4,344,520 tons; and, in 1881, the British numbered 2,251 out of a total of 2,727 vessels, and the tonnage, 4,792,118, out of 5,794,400, thus increasing the proportion of vessels and tonnage from two-thirds to four-fifths. The trade of 1881, then, of vessels other than British, amounted to only 1,002,282 tons, and would, at 10 francs per ton, have yielded a revenue of only £400,915.

In 1880, the total expenditure on the canal was about £218,900; interest and sinking funds of loan, £531,560; total, £750,460. So that, but for the British trade, instead of 13½ per cent. interest accruing to the original shareholders, there would not have been sufficient to pay even a moiety of the interest of the loans!

Similarity, with regard to the revenue realized. In 1879, it amounted to £1,214,-520; 1880; £1,672,836; 1881, £2,187,-047. The actual returns obtained from the canal will be seen from the following figures:

| | |
|---|---|
| In 1880, the expenditure on repairs was ..... | £218,898 |
| Amount set aside for interest and sinking funds..... ..... | 531,559 |
| To provide for the interest at 5 per cent. on share capital and sinking fund..... | 403,215 |
| Total..... | £1,153,972 |

| | |
|---|---|
| Which deducted from the total receipts ..... | £1,672,836 |
| Leaves a balance of... | £519,164 |

to be allotted to reserve funds, and other purposes, as enjoined in the statutes above quoted, after deducting the 15 per cent. appropriated to the Egyptian Government. Of this sum, £350,176 was divided among the original shareholders, raising their profits to 5+4.3=9.3 per cent.

In 1881, the cost of working the canal was somewhat less than in 1880, viz., £212,490, while the interest and other charges remained about the same, but the total receipts were £2,187,047; so that the sum to be divided reached £700,856, and the original shareholders pocketed 5+8.76=13.76 per cent. By arrangement, a certain number of shares are drawn to be paid off each year; those shareholders, therefore, who have got back their capital, cease to receive the annual 5 per cent. interest but are entitled to the dividend of 8.76 per cent. on it, and will continue to receive the enhanced dividend, whatever it may amount to, till the charter of the company expires in 1968. The dividend for 1882 is expected to reach 16 per cent.

Little comment is required on these figures, and there can be little doubt as to what nationality the future management of the canal should be entrusted, when four-fifths of the revenue is contributed by British trade. One cannot be surprised that there should arise a cry from British shipowners, that the time has arrived when the tax of ten francs per ton should be lowered. Abstractedly, it is a heavy burden, but relatively, it is less so, when it is remembered what economy in the expenses of transport has been effected by the saving in distance, and, therefore, in time, as well as in diminished risks and insurances. It is true that freights have fallen somewhat in proportion, and it may be said that, one year with another, the profits of the carriers are by no means so great as formerly; and it may be fairly urged, therefore, that the whole community is interested by the cost of transport, being kept at the lowest figure possible. A tax which represents so considerable a fraction of the whole freight, 16 per cent., I am informed, ought to be reduced, especially when it is no longer needed for the security of the capitalists from loss.

In approaching the consideration of the Suez Canal as a political problem, the difficulties which surround a satisfactory solution of it must at once be acknowledged. It has been seen, how, though originating in a commercial speculation, the scheme contained, from the very first, elements of a political character, which the British Government of the day could not possibly ignore; and how, as its operations progressed, sharply accentuated differences of international policy have been manifested, requiring the best efforts of diplomacy to arrange. Though, happily for England, no rupture in friendly relations has occurred, yet recent events have only too plainly shown "how great a matter a little fire kindleth," and how small a circumstance might vitally affect the interests of England, as regards her Eastern possessions, by the closure of this great thoroughfare to India. The immense importance to this country of those clauses in the concessions in which the Government declares the company to be Egyptian, subjects it to all the laws and usages of the Turkish Empire, and reserves to itself entire control in all particulars, military and civil, have been unmistakably manifest. Still more so, in the action of the Porte in insisting on the restoration of large tracts of land along the canal's course, which had been at first made over, without due consideration, to the company; for had that land still remained in their hands, it is extremely doubtful whether national susceptibilities might not have interfered with the able and successful strategic movement of our troops from Alexandria to Ismailia.

Again, the overwhelming preponderance of British trade over that of all other nationalities, added to the fact that its magnitude alone enables the Canal Company to exist, and the canal itself to be maintained, renders it imperative that that trade should not be imperilled, or its safety left dependent entirely on such strategic movements, the success of which a small error in judgment or a trifling miscalculation of time might wholly frustrate. It was pointed out, in a recent able article in the *Nineteenth Century*, that of all the naval powers England was furthest off from the Suez

Canal, and in the event of hostilities, her enemies might be first on the scene, and occupy it some days before her fleet could possibly arrive; but on the other hand, to be forewarned is to be forearmed and England possesses harbors nearer the canal than Portsmouth, and crusing ground nearer than the British Channel. If advantage be duly taken of these, and England is true to herself, the rest may be left safely to the judgment of Lord Alcester (late Sir Beauchamp Seymour), and such men as he has the good fortune to command.

But though such eventualities cannot be altogether ignored, yet there are, perhaps, other means left for procuring a more desirable solution of the desired end.

As far as can be judged from the sentiments expressed in the various organs of public opinion throughout Europe, there seems, with one exception, to be a tolerably unanimous desire that the management of the Suez Canal should be vested in British hands; just as there was at the time when Monsieur de Lesseps was anxious for the maritime powers jointly to purchase his scheme. The correspondence on that subject is published in Parliamentary paper Egypt, No. 2 (1876), and goes to show how nearly the canal was changing hands. As the practicability of that transaction was once seriously discussed, there is really nothing quixotic in a similar suggestion at the present time. To acquire the remaining shares, even at their enhanced value, would not be a financial operation beyond the power of England, which has, within the last few years, paid a much larger sum in wars than would probably be required to satisfy the demands of even the public-spirited and patriotic shareholders of the Suez Canal. England could well afford to take over the whole of the obligations and liabilities connected with it, as, with the prospect of an increase of traffic such as is now opening up, the surplus of the receipts over and above the necessary current expenses would quickly furnish the means of discharging those obligations and liabilities, while the mercantile community and public generally would not grudge a continuance of even the present high due of 8s. per ton, so long as there was the certain prospect before it of its diminution to the small figure requisite to defray the necessary expenses of the up-keep of the canal. For obvious reasons, details of calculations and figures cannot be entered into at the present time. If, however, international exigencies or individual susceptibilities should bar the way to such an amicable solution, and one profitable alike to all concerned, there remains a suggestion, which has elsewhere been made, of enabling the Ruler of Egypt to become the proprietor of a grand public work, which should never have been allowed to become the property of any private body of shareholders, but ought decidedly to have been undertaken solely and simply by the State. It is true that it is easy to be wise after the event, but it would equally be folly not to avail oneself of the wisdom when gained; and if, as was wittily remarked by the writer of the article in the *Nineteenth Century*, already adverted to, we are not only in the position of the *beati*, but the *beatissimi possidentes*, it will be odd if, with nine points of the law in our favor, we are not able to justify our proceedings. But even should this position be rendered untenable by a *force majeure*, there is yet a third resource, and that is, the construction of an alternative line of canal. This will, of course, be opposed on the ground that the several concessions conferred exclusive power on Monsieur de Lesseps for the construction of a canal across the Isthmus of Suez, east of the Damietta mouth. The exclusive power actually conferred, however, was that of forming a company for the purpose. If it excludes any other private individual from forming a company, it most assuredly did not exclude the Egyptian Government itself from making another canal anywhere it pleased within its dominions; and, therefore, the Egyptian Government is at perfect liberty to take whatever action it pleases in such a matter. But is it possible to make another maritime canal? Decidedly so; either east or west of the Damietta mouth. On the east, as far as can be judged from the line of coast surveys, a favorable approach and entrance could be formed in or about longitude 32.55, where the 5-fathom line runs nearest the coast, and from whence a pier, carried at an acute angle to the coast line on to the adjacent

shoal, would form a protection against the littoral currents, while the Bay of Pelusium would afford an enormous area for receiving so much of the Nile deposit as would be arrested by the pier. As, however, the pier would run not perpendicularly, but at an acute angle to the coast, its interceptive action would be much smaller than that caused by the Western pier at Port Said. The line of the canal could be taken through Lake Sirbon, and then through more or less cutting to the Bitter Lakes; from whence a course could be found more or less parallel to the present canal. The difficulty with regard to the supply of fresh water, which immediately suggests itself, could be overcome by pipes led from the Ismailia canal, under the maritime canal, into a reservoir, and pumped up from thence to every part of the new line. The probable cost of such a canal it is impossible to conjecture, in the absence of detailed surveys, but the difference between it and the existing line, if any, would be confined to the northern half. The economy which would be effected in the excavations by the experience already gained, would probably fully compensate for the increased depth of cutting, which might be unavoidable. A line to the westward could be found skirting the coast through the lagoon, and crossing the tidal rivers near their mouths as is now being done between Calcutta and Orissa.

A scheme for a fresh-water canal from Alexandria to Suez, *via* Cairo, attributed to the late Khedive, has lately been put forward, and advocated on the merits of its combining irrigating capabilities with those of navigation; but independent of its practicability, or otherwise either technically or financially, it is simply out of the question that England could hazard its present trade of $4\frac{3}{4}$ million tons, much less its future trade of possibly five times that amount, on a canal which would be exposed to such contingencies as are likely to occur to any fresh-water canal, whose navigability depends upon a series of locks, a class of works continually liable to derangement and injury.

An inter-oceanic canal ought, if possible, to be unencumbered throughout its entire length. Accidents, such as the wreck of a vessel, or the creation of shoals, may occur, of course, at any time; but a few days would, at the most, suffice to clear a passage through them; whereas, the subsidence of a lock could not be remedied under many months; and if the existing maritime canal be in unfriendly hands, as it assuredly will be were a rival line constructed, then what will become of England's trade?

There is no more zealous advocate of canals combining the two properties of irrigation and navigation than the writer of this paper; but works suitable for the requirements of inland navigation come under a wholly different category to those adapted for the oceanic traffic. The late enlightened and shrewd ruler of Egypt would not have failed to appreciate the difference had it been clearly explained to him, and would have quickly seen that the interests of Egypt would not be advanced by such a work; while one of the chief ends desired, viz., to supply irrigation to the Delta direct and by gravitation, can be attained at one-fifth of even the estimated outlay of a ship canal, and all the requirements of internal navigation be simultaneously secured. In properly devised schemes of delta works, such as those in India, several alternative navigable lines are led to the chief port, so that, in the event of one being blocked, others are still available; but deliberately to leave the traffic of distant countries dependent on a single line of canal, the masonry works of which a few charges of gunpowder in time of war, or an unforeseen accident in time of peace, might destroy, would, to say the least, be the gravest of mistakes—tantamount to an act of commercial, if not national, suicide.

In the event, however, of a satisfactory arrangement being come to as regards the existing canal, there remains the question how it can be best adapted to meet the requirements of the traffic, which has already outgrown its capabilities. Opinions seem to be divided as to the alternative of enlarging the present course, and that of constructing a parallel line. At first sight, it would seem as if there could be no doubt as to the former being the most economical, both in regard to first outlay and subsequent working expenses. If there is not much

of the excavated material in the banks to be removed, there can be no question as to the economy of widening the present canal over excavating a new one, while the cost of supervision for working the traffic would remain the same; whereas, if there is a double line, there must be an increased establishment, though not necessarily a doubling of its numbers. On the other hand, there would doubtless be an advantage in having a double line, both in minimising the chance of accidents, and in expediting the transit through the canal, by almost entirely obviating the necessity for stopping in sidings; though, as a low speed would still have to be maintained, ships would not be able to accomplish the voyage in twelve hours, and would therefore be obliged to spend, at least, one night in the canal, as at present. An additional advantage of a double canal would be, that in case of either becoming temporarily blocked, the whole traffic would not be suspended; a point of very great importance when the number of vessels increases so rapidly, as it seems likely to do.

It is concluded the expense of separate entrances at either end are not contemplated, but the present arrangements would be common to both lines. These, of course, could only exist, if the control is in the hands of England, or otherwise arranged for beyond the possibilities of risk in the time of war.

On the whole, however, after weighing the matter from all points of view, my own recommendation would be to enlarge the existing canal to a width of 200 feet at bottom, the dimensions of the great canal from the River Sutlej, recently opened in North India, with such slopes to the sides as the nature of the soil admits of at different points of its course, and substantially revetted with stone where necessary. The speed of vessels might then be increased to a maximum of eight miles per hour, but limited to four miles when passing one another in opposite directions. As few steam vessels have a lower speed than eight miles, there would be no necessity, except in a few instances, of their overtaking each other; especially if an interval between the starting of each vessel at daylight is made compulsory. A restriction of traffic during the night may still be necessary, unless very perfect arrangements can be made for avoiding collisions; but it would be safest to confine the voyage to daylight hours, and to make it feasible to pass through the canal between dawn and dusk.

There is yet one other phase in the political aspect for consideration, and that is, what are the principal dangers to which, in time of war, the Suez Canal would be exposed? They are:

1. A blockade at either end.
2. The removal of buoys, beacons, and necessary adjuncts to the navigation.
3. Blocking up the canal with obstacles of any kind.
4. The destruction or scuttling of vessels.
5. Last, but not least, cutting off the supply of fresh water from the Ismailia Canal.

The remedy for the first lies, of course, in the hands of the nation that commands the seas; and, if it is only careful to keep that command, it can equally anticipate and prevent any of the other dangers besetting the course of the canal itself. Cutting off the fresh-water supply could only occur in the event of another such eruption in Egypt as has lately been extinguished; and it would, no doubt, be done again, and done more effectually than it was on the last occasion. It rests entirely with England whether such an eruption shall be again possible; and whether, with the forewarnings she has received, and the experience which India has afforded her of a somewhat similar, though far graver, character, she shall not accept the position now thrust upon her, and herself keep the key of the Water Avenue that leads to her Eastern Empire.

It would be presumption on the part of the writer of this paper to offer further detailed suggestions on a matter which is intrusted to one of the ablest of diplomatists at England's command; but he cannot conclude without expressing his hope that the rumors of possible arrangements, as recently put forth in the daily journals, may prove to be inaccurate, and that it will soon become patent to the world that Egypt's extremity having made England's opportunity, the Suez Canal will no longer be allowed to

remain an apple of international discord, and that it will prove to be the particular link in a chain of providential circumstances leading to the land of the Pharaohs once more recovering prosperity, with the help of England's guidance, and maintaining it under the ægis of England's power.

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# DEFLECTIVE FORCES ON A REVOLVING SPHEROID.

By RD. RANDOLPH, C. E.

Written for Van Nostrand's Engineering Magazine.

In the discussion of this subject objections and answers have been made having reference to the principal points of the problem, but which did not require a complete formula, embracing both Eastern and Western movements, and the correction of latitude required for the spheroid. The following is a brief statement of the whole problem, and the formula expresses the horizontal force of a body moving over the surface of a revolving spheroid acting at right angles to the line of the independent movement of the body. The form of the spheroid being adjusted to the force of its revolution.

P=the point on the surface where the force is required.

L=the angle between a line normal to the surface at P and the equatorial plane.

R=the length of the normal from P to its intersection with the axis of the spheroid.

R×cos L=the radius of the circle of revolution at P.

$a$=the angle between the line of the independent movement and the meridian tangent at P.

V=the velocity of revolution at P.

$v$=the independent velocity of the body on the surface. $g$=gravitation at P.

$v \times \text{sine } a$=the eastern or western component of the independent velocity.

$V+v.\ \sin a$=the actual eastern velocity when $a$ is east of the meridian plane.

$V-v.\ \sin a$=the actual eastern velocity when $a$ is west of the meridian plane.

$\frac{V^2+2\,V.\ v.\ \sin a+v.^2 \sin a^2}{R.\ \cos L.\ g}$ = centrifugal force when $a$ is east of the meridian.

$\frac{V^2-2\,V.\ v\ \sin a+v.^2 \sin a^2}{R.\ \cos L.\ g}$ = centrifugal force when $a$ is west of the meridian.

The horizontal component of these centrifugal forces is obtained by multiplying them by $\sin L=\frac{\cos L}{\cot L}$. Therefore

$\frac{V^2+2\,V.\ v\ \sin a+v.^2 \sin a^2}{R.\ \cot.\ L.\ g}$ = horizontal component when $a$ is east of the meridian.

$\frac{V^2-2\,V.\ v\ \sin a+v.^2 \sin a^2}{R.\ \cot L.\ g}$ = horizontal component when $a$ is west of the meridian.

The component of these which is at right angles to the line of independent movement is obtained by multiplying by $\sin a$. As $\frac{V^2}{R.\ \cot L.\ g}$ is the centrifugal force of the surface at P, which is balanced by the curve of the spheroid of revolution, it will no longer be considered. Therefore

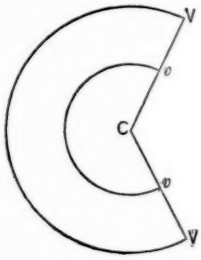
$\frac{2\,V.\ v.\ \text{sin } a^2+v.^2 \sin a^3}{R.\ \cot L.\ g}$ = component at right angles with line of easterly independent movement.

$\frac{-2\,V.v.\ \sin a^2+v.^2 \sin a^3}{R.\ \cot L.\ g}$ = component at right angles with line of westerly independent movement.

The rotation of a horizontal plane which is a part of the surface of the spheroid is measured by the angle of the sector, which is developed from the cone described by a meridian tangent at the point

about which the plane rotates. Consequently this is the measure of the deflection of any of the lines of that plane. When a body is moving along a deflecting line it is subject to a deflective force equal to the centrifugal force upon a circle whose tangent, accompanying the body, deflects at the same rate.

Let VVC be the sector described in one revolution by the meridian tangent VC = R. cot L, and let the arc $vv$ be the distance which the independent velocity $v$ would accomplish in the same time.




Then the tangent of the arc $vv$ accompanying the body moving with the velocity $v$ deflects at the same rate as the radius VC. Therefore the centrifugal force on $vv$ is the same as the deflective force of a body moving with the velocity $v$ along the radius VC. As these arcs are in proportion to the velocities with which they are described, then $V : v :: R. \cot L : Cv$, the radius of the arc $vv = \frac{R. \cot L. v}{V}$, and the centrifugal force is $v^2 \div \frac{R. \cot L. v.}{V.} \times g = \frac{V. v}{R. \cot L. g}$.

As the eastern or western component of the independent velocity is involved in the centrifugal force and the body can move along the meridian line only with its meridional component, $v$ in the above equation must be substituted by this component $= v. \cos a$. The deflective force would then become

$$v.^2 \cos a^2 \div \frac{R. \cot L. v \cos a. g}{V} = \frac{V. v. \cos a^2}{R. \cot L. g}.$$

This must be multiplied by cos $a$ for that component of it which is at right angles to the line of the independent movement, making it $\frac{V. v. \cos a^3}{R. \cot L\, g}$.

As the reaction against this deflective force is to the left of the independent movement in the southern hemisphere and to the right of it in the northern, it is towards the equator in either with an eastern movement, and towards the pole in either with a western movement. Therefore, if the independent movement is westerly, the component last found is a minus quantity when added to the centrifugal force which is always towards the equator.

The whole force acting at right angles with the line of independent movement is then

$$\frac{2\,V. v. \sin a^2 + v.^2 \sin a^3 + V. v. \cos a^3}{R. \cot L. g}$$

when $a$ is east of the meridian, and

$$\frac{-2\,V. v. \sin a^2 + v.^2 \sin a^3 - V. v. \cos a^3}{R. \cot L. g}$$

when $a$ is west of the meridian.

In the latter case the force in question will be affected with a minus sign when reduced to its numerical value, showing it to be towards the pole. When multiplied by the weight of the body at P, the result is in pounds.

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A soft alloy which attaches itself so firmly to the surface of metals, glass, and porcelain that it can be employed to solder articles that will not bear a very high temperature, can, according to *Amateur Mechanics*, be made as follows: Copper dust obtained by precipitation from a solution of the sulphate by means of zinc is put in a cast iron or porcelain lined mortar and mixed with strong sulphuric acid, specific gravity 1.85. From 20 to 30 or 36 parts of the copper are taken, according to the hardness desired. To the cake formed of acid and copper there is added, under constant stirring, 70 parts of mercury. When well mixed, the amalgam is carefully rinsed with warm water to remove all the acid, and then set aside to cool. In ten or twelve hours it is hard enough to scratch tin. If it is to be used now, it must be heated so hot that when worked over and brayed in an iron mortar it becomes as soft as wax. In this ductile form it can be spread out on any surface, to which it adheres when it gets cold and hard.

# ON THE EFFECT OF THE EARTH'S ROTATION ON BODIES MOVING ON ITS SURFACE—A CORRECTION.

By J. E. HENDRICKS.

Contributed to Van Nostrand's Engineering Magazine.

In the October number of this Magazine there was published an article by me "On the Effect of the Earth's Rotation on Bodies Moving on Its Surface," which contains several errors that I desire to correct.

In that article I obtained for the component of the deflecting force resulting from the earth's rotation about a normal axis at P, the equation,

$$f=\frac{\frac{1}{2}\frac{1}{8}\frac{1}{9}\, g\, 24\, v \sin\lambda}{2\pi R}, \qquad (2)$$

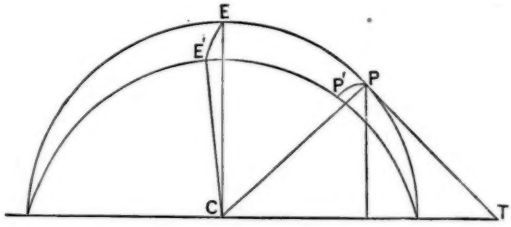
and I there stated that this equation was only correct on the supposition that the body did not change its longitude. I neglected, however, to determine the component of the force resulting from the rotation of the earth about its polar axis, which will be found to be exactly the same as that resulting from its rotation about the normal axis at P, as follows:

Let C represent the center of the earth, EE′ a part of the equator, EP=$\lambda$, the latitude of P, and let EE′=$\omega R dt$ be a very small arc of the equator.

If we suppose the meridian at P to be a material plane fixed in the sphere and revolving with it about the polar axis, and if the body passes P with a uniform velocity, $v$, it will be deflected at right angles to its line of motion by the uniform motion of the meridian plane about its polar axis, and will, therefore, in the very small time, $dt$, describe the circular arc, PP′; and if we suppose this motion to be continued on the tangent plane, while the tangent plane makes one complete revolution about PT as an axis, the locus of the body on the tangent plane will be a circle touching the normal axis at P, and the circumference of which will be $v$ multiplied by the time occupied by the plane in making one complete revolution about PT, viz., one day divided by sin $\lambda$; whence we find, as a measure of the deflecting force at P, the centrifugal force in a circle which is the locus of the body on the tangent plane, or

$$f'=f=\frac{\frac{1}{2}\frac{1}{8}\frac{1}{9}\, g\, 24\, v \sin\lambda}{2\pi R}; \qquad (2')$$

therefore the total deflecting force at P,




when the direction of the motion is in the meridian, is

$$f+f'=\frac{\frac{1}{2}\frac{1}{8}\frac{1}{9}\, g\, 24\, v \sin\lambda}{\pi R}. \qquad (a)$$

If the direction of the motion at P is not in the meridian but makes an angle $\beta$ with the meridian, then the velocity of the body, in the direction of the tangent TP, is $v \cos\beta$, instead of $v$, which being substituted for $v$ in equation ($a$) gives

$$f+f'=\frac{\frac{1}{2}\frac{1}{8}\frac{1}{9}\, g\, 24\, v \cos\beta \sin\lambda}{\pi R} \qquad (a')$$

When $\beta$ is 90°, cos $\beta$=0, and $f+f'$ becomes zero; but in this case we have from the body's motion in longitude a centrifugal force

$$F=\frac{\omega\,(R\cos\lambda-v)^2}{R\cos\lambda}=\omega\,R\cos\lambda-2\omega v+\frac{v^2}{R\cos\lambda},$$

and resolving this in the direction of the tangent plane it becomes

$$\omega\,R\cos\lambda\sin\lambda-2\,\omega\,v\sin\lambda+\frac{v^2\sin\lambda}{R\cos\lambda};$$

but of this force, the first term is just what is required to sustain the spheroidal figure of the earth, so that we have left for the efficient deflecting force, when the motion is to the west,

$$F'=-2\,\omega\,v\sin\lambda+\frac{v^2\sin^2\lambda}{R\cos\lambda},$$

and when the motion is to the east,

$$F'=2\,\omega\,v\sin\lambda+\frac{v^2\sin^2\lambda}{R\cos\lambda}.$$

Or substituting for $\omega$ its equivalent, $V\div R$, and writing $\frac{1}{2}g$ for $V^2\div R$, we get

$$F'=\left(\pm 2+\frac{24\,v}{2\pi R\cos\lambda}\right)\times\frac{\frac{1}{2}g24v\sin\lambda}{2\pi R}.\quad(b)$$

If the direction of the motion at P is not perpendicular to the meridian, but makes an angle $\beta$ with the meridian, the motion of the body in longitude at the point P will be $v\sin\beta$, instead of $v$, which being substituted for $v$ in equation $(b)$ gives

$$F'=\left(\pm 2+\frac{24\,v\sin\beta}{2\pi R\cos\lambda}\right)\times\frac{\frac{1}{2}g24v\sin\beta\sin\lambda}{2\pi R}$$

$$=\pm\frac{\frac{1}{2}g\,24v\sin\beta\sin\lambda}{\pi R}+\frac{24\,v\sin\beta}{2\pi R\cos\lambda}\times\frac{\frac{1}{2}g\,24\,v\sin\beta\sin\lambda}{2\pi R}.\quad(b)$$

As the deflecting force represented by $(a')$ is the same whether the body moves north or south at the point P, it may be written either plus or minus. Hence, adding the right hand member of $(a')$ to the first term of the right hand member of $(b')$, we get, for the resultant of the two forces when the motion of the body at P makes an angle $\beta$ with the meridian, supposing the deviation from the meridian to be westward,

$$\Sigma(f')=-\frac{\frac{1}{2}g\,24\,v\sin\lambda}{\pi R}+\frac{24\,v\sin\beta}{2\pi R\cos\lambda}\times\frac{\frac{1}{2}g\,24\,v\sin\beta\sin\lambda}{2\,\pi\,R}.$$

Now as the first term of the right hand member of this equation, which represents the sum of all the deflecting forces, whatever the direction of the motion may be, is *minus* when the motion is westward, and *plus* when it is eastward from the meridian, and the second term is always *plus*, it follows that the deflecting force is *least* when the motion is to the west, and greatest when the motion is to the east.

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*Note.*—Since the foregoing was written I have received the December Magazine, in which I find a very fair, and somewhat elaborate, criticism, by Mr. Rd. Randolph, of my paper in the October number, of which the foregoing is believed to be a correction. To most of Mr. Randolph's criticism I fully assent, as it agrees with the foregoing correction; but he has failed to supply the principal omission in my paper published in the October number, viz., the force $f$ in equation $(2')$, above, and, therefore, his result is still incomplete, and does not represent the entire deflecting force.

The only part of Mr. Randolph's criticism, which demands any reply by me, is his charge that my method of determining $f$ is "unphilosophical," "and will prove a stumbling block."

This charge is not warranted from the conception embraced in the method employed by me, but is, to a certain extent, by a verbal inaccuracy in my statement of the case. Instead of saying, as I did, "and hence will be compelled to describe a circle, and will return to P, &c." I should have said, "and hence will, at the point P, describe an indefinitely small arc of a circle, in which, if the body should continue to move, it would return to P, &c."

The actual curve described by the body on a tangent plane, if deflected by the revolving meridian, would, of course, be the spiral of Archimedes, of which P is the pole; but we only have to deal with the curve at the point P, where we know the velocity of the describing body and the amount of its angular deflection, and, consequently, know all the elements of the circle in which it is moving when in the point P. Its deflection at the point P is, therefore, the measure of the centrifugal force due the circle in which the body is moving at the point P.

# THE HOWE TRUSS BRACE, AND THE GENERAL EQUATION OF THE FOURTH DEGREE.

By JOHN D. CREHORE, Cleveland, Ohio.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE inscription of a rectangle of given width within a given rectangle is not a new problem; but the following solution, II, accurate far beyond the working limits of the *Howe Truss* brace and block, I have nowhere seen.

In the accompanying figure let ABCD be the given rectangle, or panel of the truss between the top and bottom chords; FGMN the required rectangular surface of brace; and FGB = MCN = the required brace-block section. Let O be the common center of the two rectangles; draw the diagonal BOC, also the lines OE and OH in the centers of their respective rectangles.

Take EB = AE = $a$ = given half-width.
EO = OL = $b$ = given half-length.
OH = $l$ = required half-length of brace.
FH = HG = $c$ = given half-breadth of brace.

Angle BOE = $\alpha$, given.
BOH = $\varepsilon$, required.
EOH = $\gamma$, required.

I. From the figure we have angle

$$BFG = EOH = \gamma = \alpha - \varepsilon, \quad (1)$$

$$a = c\cos\gamma + l\sin\gamma \quad (2)$$

$$b = l\cos\gamma + c\sin\gamma \quad (3)$$

$$\therefore \quad l = \frac{a - c\cos\gamma}{\sin\gamma} = \frac{b - c\sin\gamma}{\cos\gamma} \quad (4)$$

$$c\sin^2\gamma - c\cos^2\gamma - b\sin\gamma + a\cos\gamma = 0. \quad (5)$$

But $\sin^2\gamma = 1 - \cos^2\gamma$; therefore equation (5) after reducing becomes

$$\cos^4\gamma - \frac{a}{c}\cos^3\gamma + \left(\frac{a^2+b^2}{4c^2} - 1\right)\cos^2\gamma + \frac{a}{2c}\cos\gamma - \frac{b^2-c^2}{4c^2} = 0. \quad (6)$$

Take $a = 5$ feet.
$b = 7.5$ "
$c = 0.5$ "

then equation (6) gives



$$\cos^4\gamma - 10\cos^3\gamma + 80.25\cos^2\gamma + 5\cos\gamma - 56 = 0, \quad (7)$$

Solving by *Horner's* method, we find

$$\cos\gamma = .84498498 = FB = 2c\cos\gamma.$$
$$\therefore \sin\gamma = .53479004 = BG = 2c\sin.\gamma$$

since FG = 2c = 1 foot = radius in FBG.

$$\therefore \gamma = 32^\circ\ 19'\ 46.''82.$$

But $\tan\alpha = \frac{5}{7.5}$. $\therefore \alpha = 33^\circ\ 41'\ 24.''25$

$$\varepsilon = \alpha - \gamma = 1^\circ\ 21'\ 37.''43.$$
$$\sin\alpha = .554700196.$$
$$\cos\alpha = .832050294.$$

From (4), $2l = 17.118896$ feet.
= required length of brace.

This is the ordinary solution, and is exact so far as we please to carry out the decimals.

II. If we put $\alpha - \varepsilon$ for $\gamma$ in equation (5), and take the well-known trigonometrical values of $\sin(\alpha - \varepsilon)$ and $\cos(\alpha - \varepsilon)$, and also substitute $1 - \sin^2\varepsilon$ for $\cos^2\varepsilon$, remembering that $a\cos\alpha = b\sin\alpha$, we find, after reducing,

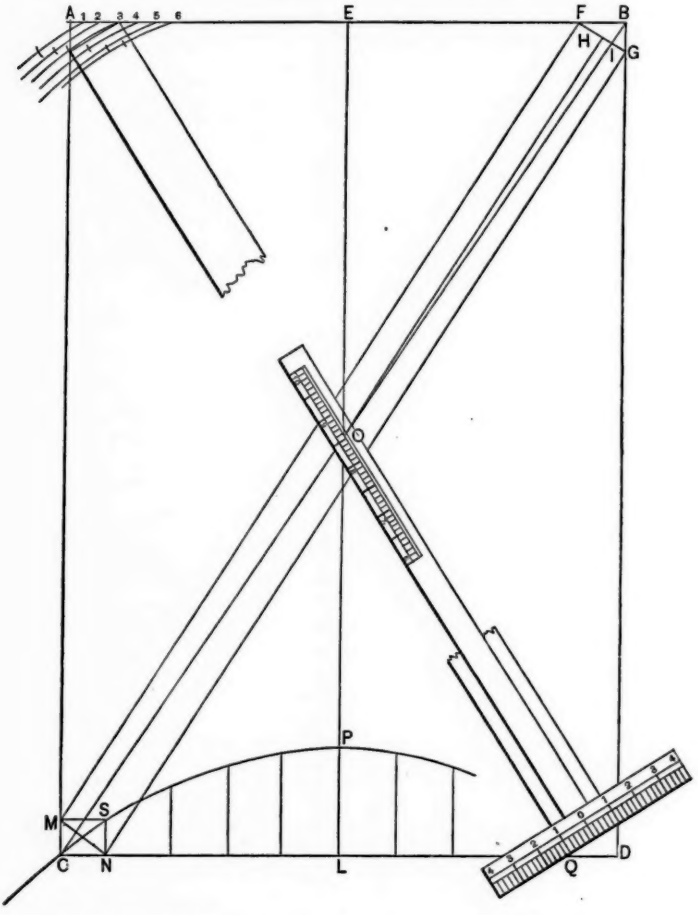
$$\sin^2\varepsilon + \frac{a\sin\alpha + b\cos\alpha - 4c\cos\alpha\sin\alpha\cos\varepsilon}{2(\cos^2\alpha - \sin^2\alpha)}$$
$$\sin\varepsilon = \tfrac{1}{2}, \quad (8)$$

Now, since $\varepsilon$ is always a small angle in practice, and $c$ is also small, no appreciable error will be committed if we put $\cos\varepsilon = 1$ in the small third term of the numerator, equation (8). Making this substitution, and making no other variation from strict rule, we have

$$\sin^2\varepsilon + \frac{a\sin\alpha + b\cos\alpha - 4c\cos\alpha\sin\alpha}{2c(\cos^2\alpha - \sin^2\alpha)}$$
$$\sin\varepsilon = \tfrac{1}{2}, \quad (9)$$

which is of the second degree with respect to the unknown quantity, and gives, using the above values of $a$, $b$, $c$, and $\alpha$,

$$\sin\varepsilon = .02374189, \text{ nearly.}$$
$$\therefore \varepsilon = 1^\circ\ 21'\ 37.''57, \quad "$$
$$\gamma = \alpha - \varepsilon = 32^\circ\ 19'\ 46.''68. \quad "$$




From (4), $2l=17.118910$ ft. "

$\sin\gamma=.5347894=BG$, "

$\cos\gamma=.8449854=FB$, "

since $FG=2c=1$ foot.

III. In the May number of this Magazine for 1881, Professor P. H. Philbrick has given, together with the exact solution by Horner's method, an approximate solution based upon the substitution of $\sin\alpha$ for $\sin\gamma$, and $\cos\alpha$ for $\cos\gamma$, in the second member of one of his fundamental equations, thereby avoiding expressions of a degree higher than the second. He also puts (continuing my notation) the length of brace,

$$2l=BC-2BI,$$

if BI in my figure were drawn at right angles to FG, as it is not.

His fundamental equations, using my figure and notation, and reducing, are

$$\sin^2\gamma+\cos^2\gamma=1 \qquad (10)$$

$$\frac{\cos\gamma}{\sin\gamma}=\frac{b-c\sin\gamma}{a-c\cos\gamma}, \qquad (11)$$

Putting $\alpha$ for $\gamma$ in the second member of (11), and combining with (10), he gets

$$\cos\gamma=\frac{b-c\sin\alpha}{\sqrt{(a-c\cos\alpha)^2+(b-c\sin\alpha)^2}} \qquad (12)$$

$$\sin\gamma=\frac{a-c\cos a}{\sqrt{(a-c\cos a)^2+(b-c\sin a)^2}} \quad (13)$$

which give $\cos\gamma=.84430985=2c\cos\gamma=$ FB,

$\sin\gamma=.53585528=2c\sin\gamma=$BG,

with the above values of $a$, $b$, $c$, and $a$.

$$\therefore\ \gamma=32^\circ\ 24'\ 7.''01.$$

$$\varepsilon=a-\gamma=1^\circ\ 17'\ 17''.24.$$

$$2l=2\sqrt{(a-c\cos\gamma)^2+(b-c\sin\gamma)^2} \quad (14)$$

$=17.118357$ ft.

Or,

$$2l=2\sqrt{a^2+b^2}-4c\sin\gamma\cos\gamma \quad (15)$$

$=17.122901$ ft.

Arranging results in tabular form for comparison, we have:

| | FB. | BG. | $\gamma$. | MF. | Error assumed. |
|---|---|---|---|---|---|
| | ft. | ft. | | ft. | |
| By equation (6).. | .84498498 | .53479004 | 32° 19′ 46.″82 | 17.118896 | $o$. |
| " " (9).. | .84498540 | .53478940 | 32° 19′ 46.″68 | 17.118910 | $\cos\varepsilon$ .0002820 |
| Error resulting... | +.00000042 | −.00000064 | −... ....0.″14 | +.000014 | |
| By eq. (12)(13)(14) | .84430985 | .53585528 | 32° 24′ 7.″01 | 17.118357 | $\sin\gamma$,+.0199102 |
| Error resulting... | −.00067513 | +.00106524 | +.... 4′ 20.″19 | −.000539 | $\cos\gamma$,−.0129347 |
| By eq. (15)... .. | ..... | . .. ..... | ..... | 17.122901 | |
| Error resulting... | ..... | ..... | ..... | +.004005 | |

From this example, which is an extreme case since the depth of brace is 1 foot and the panel comparatively small, it will be seen that equation (9) is almost absolutely exact, while equations (12), (13), (14), give results practically accurate.

The reader will smile at the precision implied in the remote decimals of this table; but he will also see that these decimals were necessary in order to show the error resulting from the use of equation (9).

IV. Again in this Magazine for December, 1878, Professor W. Allan has discussed this problem and given the graphical solution indicated at CPL in my figure.

He inscribes the two rectangles FGMN, G3MQ, having the common vertices G and M, and gets the fundamental equation

$$y^2-x^2-2by+2ax=0, \quad (16)$$

where $x=2c\cos\gamma=$FB,

$y=2c\sin\gamma=$BG,

of my notation, and eq. (16) is identical with equations (4), (5), (11).

Then, after pointing out certain relations of the areas of the rectangles, Professor Allan makes this strange remark:

"The face or hypothenuse of the block s equal to the breadth of the brace, and is the dimension given. The relation between this and one of the sides of the block leads, as Professor Woods remarks in his book, to an equation of the fourth degree, which is insoluble."

Now I suppose it is widely known that even the general equation of the fourth degree is solvable, and that *numerical* equations of any degree yield to such methods as Horner's. But it may be helpful to some to insert at the end of this article a solution of the general equation of the fourth degree, which I invented in 1865, before I knew that it was essentially Descartes' method invented long ago.

Professor Allan finally constructs the equilateral hyperbola CSP, from equation (16), the origin being at C, since, if

$$y=o,\ x=o \text{ or } 2a,$$

$$x=o,\ y=o \text{ or } 2b;$$

showing that one branch of the hyperbola passes through C and D, the other through A and B.

Then with C as a center and a radius $=2c=$the chord CS, find the point S, whose co-ordinates are manifestly $x$ and $y$. This is a neat and sufficient solution, provided great care be taken in drawing the hyperbolic arc.

V. The *Mathematical Monthly* for March, 1859, edited by Professor J. D. Runkle, contains a practical solution of this problem, by Professor D. H. Mahan, which is shown in my figure at A.

With O as a center and a radius, or radii, about equal to half the unknown

length of the brace, describe the arcs 1, 2, 3, etc., near A. Then with these points 1, 2, 3, etc., as successive centers, and a constant radius=2c=width of brace, describe arcs intersecting the former arcs. Through these points of intersection draw a curve; the point where this curve meets the side AC, is one vertex of the inscribed rectangle required; the other vertex 3 is easily found.

VI. In conclusion, I would suggest an easy solution by means of the graduated T square shown in place in the lower right hand quarter of my figure. The drawing is a sufficient explanation of the construction and use of the instrument, when it is stated that, along the graduated edge of the scale at O, there is a very narrow slit exactly in the center of the long arm of the square, in which a very fine needle point piercing the paper at O, slides as the other scale is adjusted to the given width of brace at Q. Of course the needle may be attached to a sliding Vernier plate at O, and the end-scale may also have a Vernier reading.

VII. A method of reducing the general equation of the fourth degree to the general equation of the third degree, believed to be unpublished hitherto.

Let the given equation be

$$x^4+mx^3+dx^2+hx+n=o. \qquad (17)$$

As this equation contains two pairs of roots, real or imaginary, we may suppose its first member resolved into two factors of the form

$$(x^2+sx+t)\ (x^2+s_1x+t_1)=o \qquad (18)$$

$$\therefore \quad x^2+sx+t=o \qquad (19)$$

$$x^2+s_1x+t_1=o \qquad (20)$$

each of which contains one pair of the required roots, each pair being both real or both imaginary.

The assumed co-efficients $s$, $s_1$, $t$, $t_1$, are to be determined.

The product of (19) and (20) is

$$x^4+(s+s_1)x^3+(t+ss_1+t_1)x^2+(s_1t+st_1)x+tt_1=o \qquad (21)$$

which must be identical with the given equation (17). Therefore,

$$\left.\begin{aligned} m&=s+s_1\\ d&=t+ss_1+t_1\\ h&=s_1t+st_1\\ n&=tt_1 \end{aligned}\right\} \qquad (22)$$

Eliminate $s$ and $s_1$ from (22).

$$\therefore\ mh(t+t_1)-m^2n-h^2=d(t^2-2tt_1+t_1^2)-(t^3-t^2t_1-tt_1^2+t_1^3) \qquad (23)$$

Form (22) $\quad 4dn=4dtt_1 \qquad (24)$

and $\quad -4(t+t_1)n=-4t^2t_1-4tt_1^2 \qquad (25)$

The sum of (23), (24), and (25) is, after reducing,

$$(t+t_1)^3-d(t+t_1)^2+(mh-4n)(t+t_1)+4dn-m^2n-h^2=o \qquad (26)$$

which is of the third degree as required, and gives $t+t_1$, so that $t$, $t_1$, $s$, $s_1$, may be found from (22), and therefore $x$, from (19) and (20).

It will be noticed that this reduction differs from that of Descartes in these particulars:

1. The second term of (17) is not made to disappear. 2. Four undetermined quantities are assumed instead of three. 3. The resulting equation (26) is of the third degree involving two undetermined quantities, instead of involving only one to the sixth degree.

We may continue this solution by the use of the well-known Cardan's formula, which in the present case becomes

$$t+t_1=\frac{d}{3}+\left(\frac{v}{2}+\sqrt{\frac{v^2}{4}+r^3}\right)^{\frac{1}{3}}+\left(\frac{v}{2}-\sqrt{\frac{v^2}{4}+r^3}\right)^{\frac{1}{3}} \qquad (27)$$

if we put $-\frac{d^2}{9}+\frac{1}{3}(mh-4n)=r$,

and $\frac{2d^3}{27}-\frac{d}{3}(mh-4n)-4dn+m^2n+h^2=v$.

Comparing equations (7) and (17), we find

$$x=\cos\gamma$$
$$m=-10$$
$$d=80.25$$
$$h=5$$
$$n=-56$$
$$\therefore\ r=-657.5625$$
$$v=46029.09375$$

From (27), $t+t_1=80.012392809$

From (22), $4tt_1=-224$

$$\therefore\ t-t_1=-81.400141296$$
$$t=-.6938742435$$
$$t_1=80.7062670525$$

From(22), $s+s_1=-10$

$$ss_1=d^2-(t+t_1)$$

$$\therefore\ s-s_1=9.952365107$$

$$s=-.0238174465$$

$$s_1=-9.9761825535$$

From (19), $\cos^2\gamma-0.0238174465\ \cos\gamma=.6938742435$.

$$\therefore\ \cos\gamma=.844984987;$$

which is sufficiently near to the value found by Horner's method, to establish the correctness of both solutions.

Only such values of the undetermined quantities as conduct to the desired result, have been retained, and the "irreducible case" of Cardan's rule, happily not being required in this example, has not been discussed.

However gratifying it may be to work by a complete formula, it is easy to see that Horner's method of approximation for numerical equations requires far less labor than the general solution when many decimals must be used and you have only seven decimals in your logarithmic tables.

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## MANGANESE BRONZE.*

By Mr. P. M. PARSONS, M.I.C.E.

From "Iron."

Before entering on the immediate subject of this paper, I propose to give a brief description of what has previously been done in the same direction, and to review the theoretical considerations which have led to the production of manganese bronze. Many samples of bronze made by the ancients have been found on analysis to contain a small percentage of iron, but, as far as I am aware, no traces of manganese have ever been discovered. It is not unlikely the ancients knew that the addition of iron to bronze would increase its hardness, and introduced it with that view. In more recent times, the combination of iron with the brass alloys seems to have engaged the attention of inventors considerably, and a few have also introduced manganese by reducing the black oxide, and combining it with the copper, but none of these alloys appear to have shown sufficient advantages to lead to their permanent adoption. Among the earliest of these inventors was James Kier, who, as far back as the year 1779, proposed an alloy of 10 parts of iron with 100 of copper, and 75 of zinc. Alloys of a similar character to this, but containing less iron and different proportions of copper and zinc, were subsequently introduced under the name of sterro metal and Aitch metal, and Sir John Anderson, late superintendent of the Royal Gun Factories and inspector of machinery to the War Department, carried out a number of experiments with similar alloys, and with some very good results, but no practical applications of any of them appear to have been made. The addition of iron unquestionably increased the strength and hardness of these alloys, but the experiments I have made show that they acquire these qualities at the expense of ductility and toughness, and it is probably on this account that they have not come into general use. Besides these, various other inventors have proposed to combine iron with the brass alloys; but only Mr. Alexander Parkes and the late Mr. J. D. Morris Stirling, both eminent metallurgists, proposed the use of manganese, and appear to have carried their ideas into practice. Mr. Parkes' inventions consisted in combining manganese alone with copper, and using this alloy instead of ordinary copper with zinc, to form improved alloys of brass, yellow metal, &c., of which to make sheathing, rods, wire, nails, and tubes, &c. Mr. Everitt, of Birmingham, has also lately brought forward an alloy made in a similar manner.

No comparative experiments as to the strength, hardness, or ductility, or other qualities of these alloys, have come under my notice, but I believe the only ef-

* A paper read at the meeting of the British Association at Southport.

fect of the manganese alone, is to add somewhat to the toughness and ductility of the alloys, and allow copper and zinc, of a somewhat inferior quality, to be used in the manufacture of brass and other similar alloys, which without the manganese would not stand the working necessary to shape them into the various articles for which they were destined. Mr. Morris Stirling, in 1848, however, proposed to use manganese in various brass alloys, in which iron was present, but in a very different manner from that employed by me. Mr. Stirling first combined about 7 per cent. or less of iron, with the zinc, and added to the copper a small percentage of manganese, by reducing the black oxide of manganese with the copper, in the presence of carbonaceous materials, and then added to it the requisite quantity of the iron and zinc alloy to make the improved brass required. Mr. Stirling described a method of combining the iron with the zinc by fusion, but in practice he found a more ready way of procuring the zinc and iron alloy by employing the deposit found at the bottom of the tanks used for containing the melted zinc for galvanizing iron articles; this product consists of zinc with from 4 to 6 per cent of iron, but this percentage is very variable, and this material is useless if the amount of iron is required to be adjusted with accuracy. A variety of metal made by this process was in use for some time for carriage bearings, on the London and Northwestern Railway and others, with very good results; but it has long since been superseded, and I feel satisfied it was never introduced for any purposes where the requirements were great strength, hardness, ductility, &c., which may be partly accounted for by the defect which all these alloys possess in common, viz., the great difficulty of producing sound castings of them in sand moulds with any certainty.

These, then, were the chief inventions that have come under my notice at all approaching mine in character or similarity, at the time I introduced it, and which I will now proceed to describe:

The manganese bronze is prepared by introducing and mixing with the copper (to be afterwards made into alloys, similar to gun metal, brass, bronze, or any other alloy of which copper forms a base) a small proportion of ferro-manganese. The ferro-manganese is melted in a separate crucible, and is added to the copper when in a melted state, and at a sufficiently high temperature. The effect of this combination is similar to that produced by the addition of ferro-manganese to the decarburised iron in a Bessemer converter; the manganese in a metallic state, having a great affinity for oxygen, cleanses the copper of any oxides it may contain, by combining with them and rising to the surface, in the form of slag, which renders the metal dense and homogeneous. A portion of the manganese is utilized in this manner, and the remainder, with the iron, becomes permanently combined with the copper, and plays an important part in improving and modifying the quality of the bronze and brass alloys, afterwards prepared from the copper thus treated; the effect being greatly to increase their strength, hardness, and toughness, the degrees of all of which can be modified at will, according to the quantity of the ferro-manganese used, and the proportions of the iron and manganese it contains. By these variations, together with variation in the proportion of copper, tin, and zinc employed, a most valuable range of new alloys have been produced, possessing qualities in the way of strength, hardness, and toughness, &c., far beyond anything yet obtained in any similar alloys. It will be seen that the process described of making the manganese bronze is altogether different, both in principle and effect, from Stirling's or Parkes' inventions. By Stirling's method, combining the iron with the zinc, in order to introduce it into the alloys, altogether precludes its use in any but those alloys in which a considerable portion of zinc is employed, such as brass or yellow metal. It could not be applied to any of those important alloys, of the nature of gun metal, or bronze, in which copper and tin are the chief ingredients, and which form some of the most important qualities of the manganese bronze; but an equally important difference in the manufacture of manganese bronze consists in adding the manganese in its metallic state, in the form of ferro-manganese, to the copper, by which the copper is cleansed from oxides as before explained, which can

never be the case when the manganese is reduced from the black oxide and combined with the copper by one and the same operation, in the manner pursued by Parkes and Stirling.

Another point of great importance is the very great nicety with which both the iron and manganese can be adjusted, and the effect controlled by adding the ferro-manganese to the copper, as pursued in the manufacture of manganese bronze. The amount of manganese required for deoxidizing the copper, and for permanent combination with it, having been ascertained by experience, it is found that very slight variations in quantity have a perceptible and ascertained effect in modifying the qualities of the alloys produced; that is to say, the toughness can be increased, and the hardness diminished, or *vice versa*, at will, precisely as is done in the manufacture of steel, by increasing or diminishing the dose of carbon and manganese. In preparing the ferro-manganese for use, that which is rich in manganese, containing, say, from 50 to 60 %, is preferred; this is melted with a certain proportion of the best wrought-iron scrap, so as to bring down the manganese to the various proportions required. About four qualities are made, containing from about 10 to 40 per cent. of metallic manganese. The lower qualities are used for those copper alloys in which the zinc exceeds that of the tin, and the higher qualities in which tin is used alone, or exceeds that of the zinc used in combination; and the amount of ferro-manganese added varies generally from about 2 to 4 per cent. After a number of experiments and tests, the Manganese Bronze and Brass Company, who are the sole manufacturers of the manganese bronze, have adopted the manufacture of five different qualities of manganese bronze, although other varieties can be produced for special purposes. The distinctive features, peculiarities, and purposes for which these qualities are suited, are as follows:

No. 1. In this quality the zinc alloyed with the copper is considerably in excess of the tin.

It is cast into ingots in metal moulds, and then forged, rolled, or worked hot, and made into rods, plates, sheets, sheathing, and it may also be worked cold, and drawn into tubes, wire, &c. When simply cast it has a tensile strength of about 24 tons per square inch, with an elastic limit of from 14 to 15 tons. When rolled into rods or plates it has a tensile strength of from 28 to 32 tons, with a limit of 15 to 23 tons per square inch, and it stretches from 20 to 45 per cent. of its length before breaking. When cold rolled, the elastic limit rises to over 30 tons, and the breaking strength to about 40 tons, and it still elongates about 12 per cent. before breaking.

No. 2 is similar to No. 1, but still stronger, and it can, with the required care, be cast in sand when it is required to produce castings for special purposes, possessing the greatest strength, hardness, and toughness, but it must be melted in crucibles; passing it through the reverberatory furnace injures the metal, and causes unsound castings. It is not, therefore, adapted for general brass-founders' purposes, and those only who understand its peculiarities, and are experienced in its use, should attempt casting it in sand.

One of the most important applications of this quality is that of producing articles cast in metal moulds under pressure. Blocks of this metal thus simply cast have all the characteristics of forged steel, as regards strength, toughness, and hardness, without any of its defects. It is perfectly homogeneous, and, while not possessing a fibrous texture derived from rolling or hammering, it is still fibrous in character, and this in not one but in all directions alike, and when broken shows a beautiful silky fracture. Its tensile strength is from 32 to 35 tons per square inch, and its elastic limit from 16 to 22 tons, with an ultimate elongation of from 12 to 22 per cent. It can be cast on to any object, and will shrink on to it with a force equal to its elastic limit, and when released will show an amount of resilience of about double that of steel. Thus a hoop, shrunk on to a solid cylinder of iron, gave the following results: It stretched when hot ·03 of its diameter, in the process of contraction,

and when cold and released sprang back about ·003 of its diameter. As regards hardness, it is about equal to mild steel. To ascertain its efficiency in this respect, and to compare it with gun metal, wrought iron and steel, the following tests were made, by forcing a knife edged angular die into the flat surface of each of these metals, and the No. 2 manganese bronze cast under pressure. To make a dent of equal length in each of these, the following pressures were recorded:

| | | |
|---|---|---|
| Gun metal | 12 | cwt. |
| Wrought iron | 15 | „ |
| Mild steel | 20 | „ |
| Mild steel, oil hardened | 25 | „ |
| Manganese bronze as cast | 20 | „ |
| Manganese bronze as cast, hardened by pressure | 22 to 23 | „ |

All these results point to this material as a most suitable one for the construction of hydraulic and other cylinders, required to stand great strains, and particularly for ordnance. The Manganese Bronze and Brass Company are now making arrangements for casting a block in this metal to be made into a gun, and the results are being looked forward to with much interest, as, should this prove successful, the material is likely to become a formidable rival to steel and iron, for the construction of artillery, as, although the metal itself is more costly, the simple way in which it can be manipulated will make the total cost less, and the time required to construct a gun of it will probably be less than one-fourth of that required to build up iron or steel guns.

No. 3. This is an equally important alloy with the last, but possessing altogether different qualities, and suited to different and more varied applications.

It is composed principally of copper and tin, in about the proportions of gun metal, combined with a considerable dose of ferro-manganese. Its chief characteristics are very great transverse strength, toughness and hardness, the facility with which it can be cast, and the soundness and uniformity of the castings produced, without any special care having to be taken beyond what is ordinarily given in casting gun metal. It also possesses this very important advantage in the production of large castings, that it may be melted in an ordinary reverberatory furnace without injury to the metal; very careful analysis of this alloy before and after passing through the reverberatory furnace, showing that there is no appreciable alteration in its constituents. A bar of this metal cast in sand in the ordinary way, one inch square, placed on supports 12 inches apart, requires upwards of 4,200 lb. to break it, and before breaking, it will bend to a right angle, and it will sustain from 1,700 to 1,800 lb. before taking a permanent set. These results are in every respect fully up to those of the best rolled wrought iron, as some test bars of both exhibited will show; we have, therefore, in this a material which can be cast with facility into any intricate form, which it would not be possible to forge in iron, yet possessing all its strength, toughness, and hardness. This quality of manganese bronze is used for a variety of purposes, including spur, bevel, and all kinds of toothed wheels, gearing, worms, and worm wheels, framing brackets, and all kinds of supports and connections of machines, crank pin brasses, the shells of main and other bearings of marine and other engines, axle-boxes, and other parts of locomotive engines, and it has been found admirably adapted for statuary and art purposes generally, being much admired for its fine color, but the latter quality is quite a matter of taste, and the members of the association will be able to form their opinion thereon by examining the beautiful clock and ornaments, kindly lent by Messrs. Elkington & Co., made of the manganese bronze. The metal also seems to be peculiarly adapted for large bells. The advantages in this latter application are that bells cast from it possess the same or greater sonorousness, with a more mellow tone, and are at the same time so tough that they cannot by any means be cracked like bells made of ordinary bell metal, which is obliged to be made brittle in order to acquire the requisite sonorousness. The sound of a bell is also, to some extent, a matter of taste, and those who take an interest in this question may form an opinion as to the suitableness of the manganese bronze

for this purpose by sounding the one exhibited.

But the most important application from a commercial point of view is undoubtedly that of steamship propellers. Owing to the great strength of this metal, and its non-liability to corrosion, propellers of it can be made thinner than even those of steel; the surface is beautifully smooth, and when cast they are theoretically true to form, whereas in steel propellers allowance has to be made against the corrosion which takes place, and their deficiency in toughness, by increasing their thickness, and their form becomes distorted in the annealing oven they have to pass through after being cast. For these reasons the manganese bronze has a great advantage over steel. It has been proved conclusively by the logs of a number of steamships that have had their steel propellers replaced by manganese bronze blades that their speed has been increased, and the consumption of coal diminished, while the weight, vibration, and strain on the ship and machinery is considerably reduced. In addition to this, all these advantages are secured at a considerably less ultimate cost than by the use of steel, taking it upon the average life of a vessel; for although the first cost of a manganese bronze propeller, or a propeller with manganese bronze blades, is double that of steel, it is indestructible, whereas at the end of about every three years, the steel blades become so pitted and corroded that their renewal will be indispensable, which brings up the total cost of the steel blades on an average to two or three times that of manganese bronze. That the manganese bronze propellers are incorrodible, and in every other respect efficient, has now been proved by experience, as some have been at work approaching three years, and are as perfect in every respect as when first applied. Some time after introduction of the No. 3 quality for propellers, the No. 2 was used for some propeller blades, as fears were entertained as to the No. 3 setting up galvanic action and corroding the stern frames. Most of these propellers stood well, but some of the blades failed, and it was found on examination that the castings were unsound, owing to the metal having become deteriorated by melting in a reverberatory furnace. In consequence, it has now been determined to adhere solely to the No. 3, as this quality has always given the greatest satisfaction, both as to its facility in casting and efficiency under trial; and further experience proves the supposed galvanic action to be only a myth, or if there should be a tendency to it, it is effectually prevented by lining the inside of the stern frame with zinc strips. A proof of its soundness and tenacity was shown in an accident which occurred to one of the blades of the Garth Castle, at its launch from the yard of Messrs. John Elder & Co., in 1880, when one of the blades came in contact with the jetty, and was bent round without even a crack to nearly a right angle, and was afterwards hammered back cold to its original form without detriment.

The other qualities, Nos. 4 and 5, of the manganese bronze, have no particular claims to strength, but are most effective for the purpose of bearings, slide valves, slide blocks, piston rings, &c., and in all situations where friction occurs, and much more durable than ordinary gun metal. Before concluding, I may add a few words on the art of brass founding generally, and I cannot help saying that, as at present practised, it is very far behind what might be expected in these days of progress. In the manufacture of iron and steel an amount of scientific knowledge has been brought to bear, which elevates these industries into scientific processes, but I can discover nothing of the kind in bronze and brass founding—everything is there done by the rule of thumb, and that in a most clumsy manner. The idea of combining the various metals to form the alloys required in atomic proportions, does not seem to have been ever entertained, and even the books written for the practical guidance of brassfounders, ignore this important principle altogether. I must not be understood as applying this remark to Dr. Percy, or Mr. Mallet, and other scientific metallurgists, who have drawn attention to the subject, and made valuable suggestions respecting it in their well-known works, but I allude to that class of books generally termed handbooks, and the like, which contain instruction of the most clumsy and unscientific character, for making different alloys, thus for gun metal the proportions given are 1 lb. of copper to 2 ozs. of tin, or

if required to be harder 2¼ ozs., or 2½ ozs., and so on; then, as regards brass, it may be 70 lb. of copper and 30 lb. of zinc, or 60 lb. of copper and 30 lb. of zinc, or 60 lb. of copper and 40 lb. of zinc, for yellow metals. Now, not one of these alloys or others described are in atomic proportions, and that is the reason why unsatisfactory results are constantly occurring in ordinary brass founding; not only are the copper alloys thus produced weak, soft, spongy and porous, but it is a constant occurrence that the constituents vary in different parts of the casting.

This is the case principally in the gun metal and bronze alloys. The surplus tin above that forming a definite alloy in atomic proportions, seems to be held in mechanical suspension, which separates by liquation, and collects at the top of the casting as it cools and solidifies, causing the well-known tin spots, sponginess, &c. The only remedy the ordinary brassfounder has for this, is to use as large a proportion of scrap metal as he can get—he does not know why, he only knows that he gets better castings by using it, but the true reason is that the scrap metal has adjusted its constituents in atomic proportions during the several re-meltings it has undergone, any surplus tin or zinc being got rid of by liquation and oxydation, but if in the original manufacture of the alloy the metals are combined in atomic proportions, nothing of this kind happens, the castings are sound and the alloys homogeneous. In the manufacture of manganese bronze, this principle is always kept in view, and all the different qualities produced have the metals they are composed of combined in atomic proportions.

Whether by this a really chemical combination is effected it is difficult to say, but this much I can vouch for, that the alloys thus produced are finer in texture, more homogeneous, stronger, and of a very much more stable character, than when not so combined; thus in the No. 3 quality the addition of ¼ per cent. of tin, instead of making it harder and stronger, as it ought to be, according to the ordinary accepted ideas, actually makes it softer, weaker, and the grain coarser, and the same thing occurs if the additional tin is increased ½ or 1 per cent. until the tin arrives at another definite atomic proportion, when an alloy of a different character appears, but it then again becomes close grained, sound, homogeneous and stable. As a further proof of the soundness of this theory, the No. 3 quality may be passed through an ordinary reverberatory furnace, and although, in being thus treated, it is exposed for a considerable time to the action of an oxydizing flame, no appreciable diminution of the tin in its composition has been detected. Then, again, both the No. 1 and No. 2 may be remelted several times in the crucible, if it is done with care, without any alteration of their components. It is well known how difficult it is to melt brass and yellow metal, even in a crucible, when every precaution is taken, without some of the zinc escaping in fumes; this also, to a certain extent, occurs in melting the No. 1 and No. 2 manganese bronze, but the zinc apparently carries with it its atomic complement of copper, so that the proportions of what remains are not disturbed. I am led to this belief, not only by examining the metals after re-melting, but by the color of the condensed fumes, which, instead of being white as they are when produced from zinc alone, have a beautiful pink color, which I can only attribute to the presence of copper. Another and perhaps still more palpable proof of the value of combining the metals in their atomic proportions, is that, when this is done, the specific gravity of these alloys is perceptibly increased over those not so combined, even though in the latter case the heavier metal be in excess. I was much struck by this fact in taking the specific gravity of some No. 1 manganese bronze, which contains a large amount of zinc, and which, judging by its constituents, ought to be a comparatively light metal; but the trial proved that it was about equal to that of ordinary gun metal, composed of copper and tin, and very considerably above the mean weight of the metals composing it, indicating to my mind that these metals must have combined in such a manner as each to fit into and fill up the infinitesimal spaces between the molecules of the other, and if not actually forming what chemists would admit to be a perfect chemical combination, certainly more nearly approaching it than when the

metals are mixed together in the haphazard manner usually prevailing. I have no doubt that these combinations and the stable quality of the manganese bronze alloys is also due very materially to the action of the metallic manganese on the copper, in freeing it from the oxides it contains, and thus bringing the metals added to it into actual contact, and enabling them to combine in a more perfect manner than has been accomplished hitherto.

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# ACCOUNT OF SOME TESTS OF RIVETED JOINTS FOR BOILERWORK.

By CHARLES HENRY MOBERLY, M. Inst. C.E.

From Selected Papers of the Institution of Civil Engineers.

Having to design the joints for some steel boilers which the author's firm had to construct, in the spring of 1881, he decided to be guided by the following, as the most suitable data of which he had any knowledge:

1. Some double-riveted lap joints of $\frac{5}{16}$-inch Landore S plates, with Landore steel rivets, tested by Mr. Kirkaldy for the author's firm in 1879, giving results as under:

Breaking strength of the solid plate per square inch = 25.85 tons.

Breaking strength of the plate in the joint per square inch of original area fractured = 23.21 tons.

Shearing strength of rivets in the joints per square inch = 19.4 tons.

2. Professor Kennedy's experiments on steel-riveted joints, made for the Research Committee of the Institution of Mechanical Engineers, from which the following is taken as a fair conclusion:

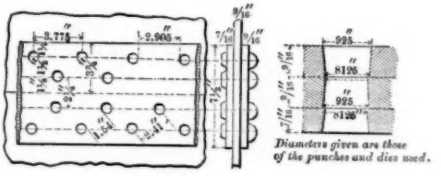
Breaking strength of the solid plate per square inch = 29 tons.

Breaking strength of the plate in the joint per square inch of original area fractured = 33 tons.

Shearing strength of rivets in the joints per square inch = 22 tons.

The discrepancy between these two sets of conclusions is considerable, but not greater, perhaps, than is continually met with, as yet, in experiments on riveted steel-plate joints. The joint designed for the boilers in question was a double-riveted butt-joint with double covers, the inside cover being $\frac{7}{16}$-inch thick, and the outside one $\frac{5}{16}$ inch thick, to bear the caulking, as shown in Fig. 1, viz:

Fig. 1




Pitch of rivets, 3.775 inches.

Distance between rows of rivets, 1.5 inch.

From centre of rivets to edge of plate, 1.125 inch.

Lap, 3.75 inches.

Diameter of rivets, $\frac{3}{4}$-inch nominal.

" punch, $\frac{13}{16}$ inch = 0.8125 in.

" " $\frac{13}{16} + \frac{1}{8} \times \frac{9}{16} = 0.925$ inch.

Mean diameter of holes = $\frac{1}{2}$ (0.8125 + 0.925) = 0.8687 inch, say 0.87 inch. Net length between the holes along the straight line = 3.775 − 0.87 = 2.905 inches for each pitch; and along zigzag line = 2 (2.41 − 0.87) = 3.08 inches.

Area of one rivet $\frac{13}{16}$ inch in diameter = 0.5185 square inch; hence rivet area

to resist shearing $=4 \times 0.5185 = 2.074$ square inch per pitch. Net area of the plate between the holes along the straight line $=\frac{9}{16} \times 2.905 = 1.634$ square inch, and area of solid plate per pitch $=\frac{9}{16} \times 3.775 = 2.123$ square inches.

The breaking strength of the joint came out as follows:

| | By tests of $\frac{5}{16}$ inch plate joints. | By Professor Kennedy's data. |
|---|---|---|
| Solid plate..... | $2.123 \times 25.85 = 54.88$ tons. | $2.123 \times 29 = 61.57$ tons. |
| Through holes..... | $1.634 \times 23.21 = 37.93$ " | $1.634 \times 33 = 53.92$ " |
| Shearing rivets..... | $2.074 \times 19.40 = 40.24$ " | $2.074 \times 22 = 45.63$ " |
| Least ratio of strength..... | $\frac{37.93}{54.38} = 0.69$ " | $\frac{45.63}{61.57} = 0.74$ " |

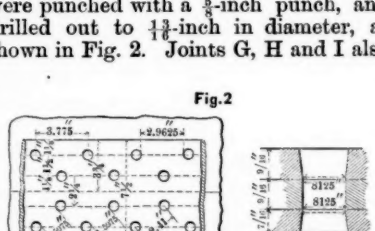
These results are all with punched and unannealed plates; and as it is generally admitted that the strength of joints is increased by drilling the holes and annealing the plates—and either or both operations could be resorted to if necessary—the author considered the joint, as designed, satisfactory for the purpose for which it was intended. But, having regard to the uncertainty still attaching to the strength of steel-riveted joints for boilers, it seemed desirable to have some tests made, and sample joints were prepared accordingly. The result of these tests was so different from what was expected, and so unsatisfactory otherwise, that further experiments were made in order to determine the proper proportion for these particular joints. All these tests, taken together, make a fairly complete series for the form of joint of $\frac{9}{16}$-inch steel plates in question.

In order to determine the rules which should regulate the proportions of all descriptions of riveted joints, a sufficient number of results of tests must be compared. Although a good many such results have, from time to time, been made public, many of them are incomplete, and more appear to be required before safe conclusions can be deduced for practice.

The author offers the present account of tests as a contribution towards such a collection. The plates tested were all of Landore S quality, $\frac{9}{16}$-inch thick, and the rivets were of Landore rivet steel. A few tests of single-riveted lap-joints for the circular seams of the same boilers were made together with the others, and will be included in this account. The whole of the tests were carried out by Mr. D. Kirkaldy, copies of whose reports are annexed (numbered 1 to 7).

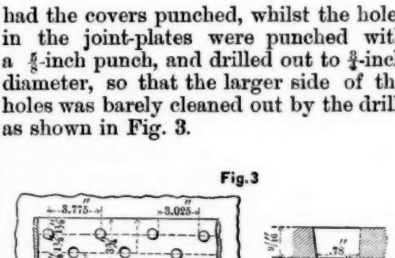
The first set of specimens consisted of nine joints (marked A, B, C, D, E, F, G, H and I), and six rivets (Annexed Reports, Nos. 1, 2 and 3). Joints A, B and C had all the holes punched as already described and shown in Fig. 1. Joints D, E and F had the holes in the covers punched, but those in the joint-plates were punched with a $\frac{5}{8}$-inch punch, and drilled out to $\frac{13}{16}$-inch in diameter, as shown in Fig. 2. Joints G, H and I also

Fig. 2



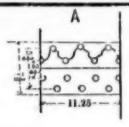
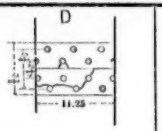
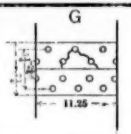
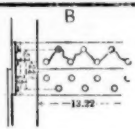
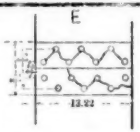
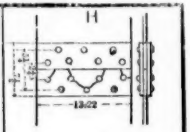

had the covers punched, whilst the holes in the joint-plates were punched with a $\frac{5}{8}$-inch punch, and drilled out to $\frac{3}{4}$-inch diameter, so that the larger side of the holes was barely cleaned out by the drill, as shown in Fig. 3.

Fig. 3




It was intended to have all the joints shaped like B, E and H, Fig. 4; but Mr. Kirkaldy objected to this form, because he considered the results would not be reliable, and wished to have them all shaped like A, D and G, Fig. 5. It was

REPORT No. 1.—Results of Experiments to Ascertain the Ultimate Tensile Strength of Six Riveted Joints received from Messrs. Easton and Anderson. All Steel Plates. Nominal thickness, nine-sixteenths of an inch.

| Sketch of Joint with Sizes | A  | D  | G  | B  | E  | H  |
|---|---|---|---|---|---|---|
| Test No. and thickness.... | P. 2125 $\frac{9}{16}$ inch. | P. 2134 $\frac{9}{16}$ inch. | P. 2143 $\frac{9}{16}$ inch. | P. 2128 $\frac{9}{16}$ inch. | P. 2137 $\frac{9}{16}$ inch. | P. 2164 $\frac{9}{16}$ inch. |
| Description of joint..... | Butt double riveted. | Butt double riveted. | Butt double riveted. | Butt double riveted. | Butt double riveted. | Butt double riveted. |
| Machine or hand-riveted... | Machine. | Machine | Machine. | Machine. | Machine. | Machine. |
| Rivet holes, per your description. | "Punched $\frac{13}{16}$." | "Punched $\frac{5}{8}$ and drilled $\frac{13}{16}$." | "Punched $\frac{5}{8}$ and drilled $\frac{3}{4}$." | "Punched $\frac{13}{16}$." | "Punched $\frac{5}{8}$ and drilled $\frac{13}{16}$." | "Punched $\frac{5}{8}$ and drilled $\frac{3}{4}$." |
| Plates, Brand. | | | | | | |
| Plates, width and thickness. | 11.25 × 0.540 | 11.25 × 0.545 | 11.25 × 0.540 | 13.22 × 0.545 | 13,22 × 0.545 | 1 322 × 0.545 |
| Plates, sect. area, gross.... | 6.075 | 6.131 | 6.075 | 7.205 | 7.205 | 7.205 |
| | lbs. tons. | lbs. tons. | lbs. tons. | lbs. tons. | lbs. tons. | lbs. tons. |
| Stress total..... | 263,340 = 117.5 | 263,690 = 117.7 | 256,180 = 114.3 | 288,620 = 128.8 | 323,230 = 144.3 | 319,910 = 142.8 |
| Stress per square inch of gross area, joint. | 43,348 = 19 3 | 43,009 = 19.1 | 42,169 = 18.8 | 40.058 = 17.9 | 45,861 = 20.0 | 44,401 = 19.8 |
| Stress per square inch of plates, solid. | 67,537 = 30.2 | 67,380 = 30.1 | 69,105 = 30.8 | 66,747 = 29.7 | 67,260 = 30.0 | 68,612 = 30.6 |
| Ratio of joint to solid plate, percentage. | 64.19 | 63.83 | 61.02 | 60.02 | 66.70 | 64.71 |
| Where fractured..... | Plate at rivet holes, silky. | Plate at rivet holes, silky. One rivet sheared. | Plate at rivet holes, silky and granular, Two rivets sheared. | Plate at rivet holes. silky. | Plate at rivet holes, silky. One rivet sheared. | Plate at rivet holes, silky and granular. Two rivets sheared. |
| Rivets: dia., area and number. | Steel 0.81 = 0.515 × 6 × 2 | Steel 0.81 = 0.515 × 6 × 2 | Steel 0.75 = 0.441 × 6 × 2 | Steel 0.81 = 0.515 × 7 × 2 | Steel 0.81 = 0.515 × 7 × 2 | Steel 0.75 = 0.441 × 7 × 3 |
| Rivets: sectional area, total square inches. | 6.180 | 6.180 | 5.292 | 7.210 | 7.210 | 6.176 |
| Shearing stress per sq. inch of rivet area. | 42,611 = 19.0 | 42,668 = 19.0 | 48,408 = 21.6 | 40,031 = 17.9 | 44,831 = 20.0 | 51,799 = 23.1 |
| Tensile stress per sq. inch of rivet area. | 64,362 = 28.7 | 64,362 = 28.7 | 64,362 = 28.7 | 74,362 = 28.7 | 64,362 = 28.7 | 64,362 = 28.7 |
| Ratio of shearing to tensile, percentage. | Rivets not sheared. | One rivet sheared. | Two rivets sheared. | Rivets not sheared. | One rivet sheared. | Two rivets sheared. |

Reshaped here to pitch of riveting as shown above. Tested as shaped by you as shown above. (Signed) DAVID KIRKALDY.

REPORT No. 2.—SUMMARY OF THE RESULTS OF EXPERIMENTS TO ASCERTAIN THE ELASTIC ALSO OF SIX STEEL RIVETS, RECEIVED

Plates—all cut Lengthway

| Specimens out of Riveted Joint. | Test No. | Thickness. | Stress. Elastic per Square Inch. | Stress. Ultimate per Square Inch. | Ratio of Elastic to Ultimate. | Contraction of Area at fracture. | Stress per Square Inch of fractured Area. | Extension-set in 5 Inches. At 50,000 lbs. per Square Inch. | Extension-set in 5 Inches. At 60,000 lbs. per Square Inch. | Extension-set in 5 Inches. Ultimate. | Appearance of fracture. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | In. | Lbs. Tons. | Lbs. Tons. | % | % | Lbs. | % | % | % | |
| P 2, 125. A | 2,126 | .53 | 33,300 | 58,455 | 55.0 | 48.6 | 133,386 | 4.52 | 9.64 | 36.4 | Silky |
| | 2,127 | .55 | 36,200 | 66,620 | 54.3 | 48.5 | 129,473 | 5.48 | 12.04 | 36.8 | " |
| | Mean.... | | 37,250 = 16.6 | 67,537 = 30.2 | 54.6 | 48.5 | 131,429 | 5.00 | 10.84 | 36.6 | |
| P 2, 135. D | 2,136 | .56 | 35,800 | 67,440 | 53.0 | 42.1 | 116,561 | 5.08 | 11.38 | 35.6 | " |
| | 2,137 | .54 | 35.800 | 67,320 | 53.1 | 49.6 | 133,648 | 5.22 | 11.46 | 36.8 | " |
| | Mean.... | | 35,800 = 16.0 | 67,380 = 30.1 | 53.0 | 45.8 | 125,104 | 5.15 | 11.42 | 36.2 | |
| P 2, 143. G | 2,144 | .55 | 37,800 | 69,920 | 54.0 | 46 0 | 129,699 | 3.18 | 6.98 | 34.2 | " |
| | 2,145 | .53 | 36,700 | 68,290 | 53.7 | 46.9 | 128.802 | 4.76 | 10.48 | 36.0 | " |
| | Mean.... | | 37,250 = 16.6 | 69,105 = 30.8 | 53.8 | 46.4 | 129.250 | 3.97 | 8.73 | 35.1 | |
| P 2, 128. B | 2,129 | .54 | 35,800 | 66,835 | 53.5 | 47.3 | 131,957 | 4.96 | 11.38 | 35.2 | " |
| | 2,130 | .55 | 35,300 | 66,660 | 52.9 | 49.1 | 130,189 | 5.34 | 12.38 | 35.8 | " |
| | Mean.... | | 35,575 = 15.8 | 66,747 = 29.7 | 53.2 | 49.2 | 131,073 | 5.15 | 11.88 | 35.5 | |
| P 2, 137. E | 2,138 | .55 | 35,400 | 67,415 | 52.5 | 46.4 | 125,901 | 4.64 | 10.04 | 35.6 | " |
| | 2,139 | .54 | 35,200 | 67,105 | 52.4 | 47.9 | 128,955 | 5.02 | 11 10 | 36.4 | " |
| | Mean.... | | 35,300 = 15.7 | 67,260 = 30.0 | 52.4 | 47.1 | 127,428 | 4 83 | 10.57 | 36.0 | |
| P 2, 146. H | 2,148 | .55 | 37,800 | 69,990 | 54.0 | 41.8 | 120,279 | 3.48 | 7.06 | 33 6 | " |
| | 2,147 | .54 | 36,500 | 67,235 | 54.2 | 52.7 | 142,378 | 5.10 | 11.42 | 37.2 | " |
| | Mean.... | | 37,150 = 16.5 | 68,612 = 30.6 | 54.1 | 47.2 | 131,328 | 4.29 | 9.24 | 35.4 | |
| | Total Mean | | 36,337 = 16.2 | 67,773 = 30.3 | 53.5 | 47.3 | 129,268 | 4.73 | 10.38 | 35.8 | |

finally arranged to try both forms, and the joints were shaped accordingly, as shown in Figs. 4 and 5.

Finding that the plate broke in all these joints, the remaining three, C, F and I, were used to ascertain the shearing strength of the rivets by drilling out four rivets, and leaving three only on each side, as shown in Fig. 6 (Report No. 3).

The riveting in all these experimental joints was done by a hydraulic riveter, with an accumulator placed next to the machine, and the pressures given are those in the accumulator. In the nine joints now under consideration this pressure was 35 tons.

The plates were not annealed in any of the joints tested.

It will be most convenient to consider the results of the rivet shearing tests first (Reports Nos. 2 and 3).

The rivets happened to be rather bare in diameter, so that, the same rivets being used in all cases, those for the $\frac{13}{16}$-inch holes had to be longer than would other-

AND ULTIMATE TENSILE STRENGTH AND QUALITY OF THE STEEL IN SIX RIVETED JOINTS; FROM MESSRS. EASTON AND ANDERSON.

Rivets.

| Nominal Size of Rivets. | Test No. | Original | | Stress. | | Ratio of Elastic to Ultimate. | Fractured. | | | | Stress per Square Inch of fractured Area. | Extension. | Appearance of fracture. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Diar. | Area. | Elastic per Square Inch. | Ultimate per Square Inch. | | Diar. | Area. | Difference. Area. | Difference. Per cent. | | | |
| | P | In. trnd | Sq. In. | Lbs. Tons. | Lbs. Tons. | % | In. | % | | | Lbs. | | |
| $\frac{3}{4}$ in. dia. | 2154 | .504 | .200 | 37,500 | 66,120 | 56.7 | .32 | .080 | .120 | 60.0 | 165,300 | Too short for ascertaining the Extension. | Silky. |
| " | 2153 | " | " | 37,400 | 65,880 | 56.7 | .33 | .085 | .115 | 57.5 | 155,011 | | " |
| " | 2155 | " | " | 37,400 | 65,060 | 57.4 | .31 | .075 | .125 | 62.5 | 173,493 | | " |
| " | 2152 | " | " | 36,800 | 64,510 | 57.0 | .31 | .075 | .125 | 62.5 | 172,026 | | " |
| " | 2157 | " | " | 36,200 | 64,320 | 56.2 | .31 | .075 | .125 | 62.5 | 171,520 | | " |
| " | 2156 | " | " | 34,500 | 60,280 | 57.2 | .30 | .071 | .129 | 64.5 | 169,802 | | " |
| | | Mean... | | 36,633=16.3 | 64,362=28.7 | | | | | 61.6 | 167,859 | | |

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wise have been the case. Thus the rivets for the $\frac{13}{16}$-inch holes were upset much more than those for the $\frac{3}{4}$-inch holes.

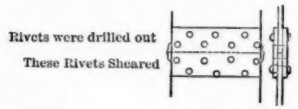
The tensile breaking strain (Report No. 2) was 28.7 tons per square inch, whilst the shearing strains were:

| | | |
|---|---|---|
| In C, with holes punched $\frac{13}{16}$-in., | 23.8 | tons per sq. in. |
| In F, with holes punched $\frac{3}{4}$-in., and drilled out to $\frac{13}{16}$-in. | 24.2 | " " " |
| In I with holes punched $\frac{3}{4}$-in., and drilled out to $\frac{7}{8}$-in. | 25.8 | " " " |
| Mean shearing strain....=24.6 | | " " " |

In these cases, therefore, the shearing strain was $\frac{24.6}{28.7} \times 100 = 85.7$ per cent. of the tensile strain. But it will be observed that the lowest tensile strength in report No. 2 is considerably below all the others; it may, therefore, be more fair to take the mean of the four middle tests only omitting the highest as well as the lowest. This gives the tensile strength=29 tons per square inch; and the shearing strength becomes $\frac{24.6}{29} \times 100$

REPORT No. 3.—Results of Experiments to Ascertain the Ultimate Shearing Strength of Three Riveted Joints received from Messrs. Easton and Anderson.

Steel Plates, nominal thickness, nine-sixteenths of an inch.




| Test. No. | Description. | Rivets. Diameter Area and Number. | Sect. Area. | Shearing Stress. Total. | Per Square Inch. |
|---|---|---|---|---|---|
| P | | Inch. Sq. In. | Sq. In. | Lbs. Tons. | Lbs. Tons. |
| 2131 | Punched holes, $\frac{13}{16}$ C | Steel .81=515×3×2 | 3.090 | 164,880=73.6 | 53,359=23.8 |
| 2140 | Punched $\frac{5}{8}$, bored $\frac{13}{16}$ F | Steel .81=515×3×2 | 3.090 | 167,810=74.9 | 54,307=24.2 |
| 2149 | Punched $\frac{5}{8}$, drilled $\frac{3}{4}$ (I) | Steel .75=441×3×2 | 2.646 | 152,790=68.2 | 57,774=25.77 |

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Fig.4

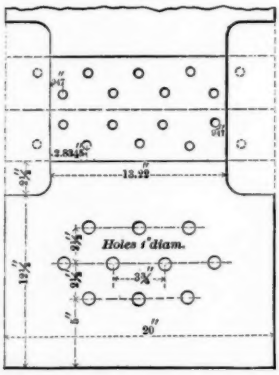
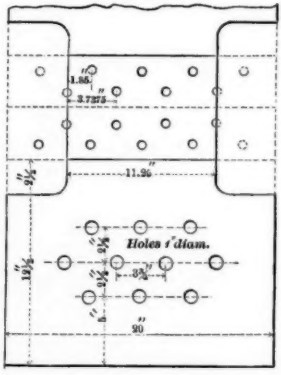



Fig.5




=84.82 per cent. of the tensile strength. Thus the shearing-strength of the rivets may be considered to be 85 per cent. of their tensile strength.

The breaking of joints A, B, D, E, G and H must be considered next. Here it may be explained that all the joints for these experiments were riveted up for the full width of the plates, as shown in dotted lines, and caulked on the edges as they would be in boiler work; they were afterwards shaped to the required form.

Report No. 1 gives the results of the tests, and shows the lines of fracture in each case, and, with the assistance of Figs. 1 to 5 and the particulars of the holes already given, the length of the line of fracture, the original sectional area along that line, and the original sectional area of rivets sheared is obtained.

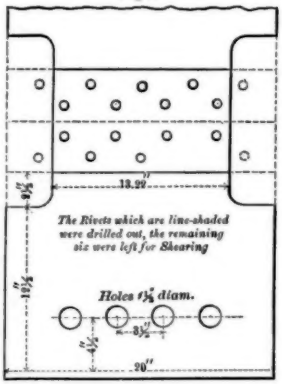
1. Joints A and B, with $\frac{13}{16}$-inch holes, punched in the ordinary way.

A broke through the rivet holes with

117.5 tons; length of fracture= 9.24 inches; area of fracture = 9.24 × 0.54=5 square inches; strength of plate per square inch of fracture $=\frac{117.5}{5}=$ 23.5 tons$=\frac{23.5}{30.2}=0.778$ of solid plate; ratio of strength of joint to solid plate =64.19 per cent.

B broke through the rivet-holes with 128.8 tons; length of fracture=10.27 inches; area of fracture=10.27×0.545= 5.6 square inches; strength of plate per square inch of fracture $=\frac{128.8}{5.6}=23$ tons $=\frac{23}{29.7}=0.774$ of solid plate; ratio of strength of joint given in report No. 1 is 60.02 per cent.

Fig. 6



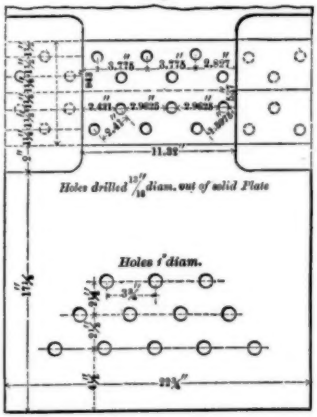

But this is not the correct ratio of the strength of the joint, when used in a boiler, because it may fairly be assumed that the fracture would have continued in a zigzag line in the continuous joint, instead of running along the straight line of rivets from the two outer rivets to the edge, as it did in this case. The specimen being 13.22 inches wide, the length of fracture along the zigzag line would have been 10.77 inches, instead of 10.27 inches, and its breaking strength would have been $\frac{10.77}{10.27}\times 128.8 = 135$ tons, making the strain per square inch of gross area of joint $=\frac{135}{7.2}=18.75$ tons.

Hence the ratio of strength of the joint becomes $\frac{18.75}{29.7}\times 100 = 63.13$ per cent., which corresponds fairly with the result of joint A.

2. Joints D and E, with holes punched $\frac{5}{8}$ inch, and drilled out to $\frac{13}{16}$ inch in diameter.

D broke with 117.7 tons, by shearing one rivet and breaking along a line of fracture=6.72 inches; area of fracture= 6.72×0.545=3.66 square inches; sheared area of one rivet=2×0.515=1.03 square inch; shearing strain of ditto=1.03 × 24.6=25.34 tons; leaving 117.7−25.34 =92.36 tons to break 3.66 square inches of plate; hence, strength of plate per square inch of fracture $=\frac{92.36}{3.66}=25.23$

Fig. 7



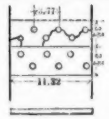
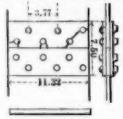
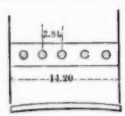
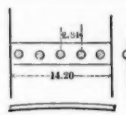

tons $=\frac{25.23}{30.1}=0.838$ of solid plate; ratio of strength of joint to solid plate = 63.83 per cent., as per report No. 1.

But it must be observed that all the four half-rivets were more or less displaced sideways, though they were not entirely forced out of the joint. The holes were, of course, elongated. The half-hole on the right side measured $\frac{7}{8}$ inch, and the hole in which the rivet had been sheared measured $1\frac{5}{16}$-inch full lengthways, after testing, as shown in Fig. 8.

E broke with 144.3 tons, by shearing one rivet and breaking along a line of

REPORT No. 4.—Results of Experiments to Ascertain the Ultimate Tensile Strength of Four Riveted Joints received from Messrs. Easton and Anderson.

All Steel Plates. Nominal thickness, nine-sixteenths of an inch.

| Sketch of Joint with Sizes | K  | L  | M  | N  |
|---|---|---|---|---|
| Test No., and thickness | P 2945 $\frac{9}{16}$ inch. | P 2948 $\frac{9}{16}$ inch | P 2951 $\frac{9}{16}$ inch | P 2954 $\frac{9}{16}$ inch. |
| Description of joint | Butt, double-riveted | Butt, double riveted. | Lap, single-riveted. | Lap, single-riveted. |
| Machine or hand-riveted | Machine. | Machine. | Machine. | Machine. |
| Rivet holes | Plate drilled, covers punched. | Plate drilled, covers punched. | Punched. | Punched. |
| Plates. Brand. | | | | |
| Plates, width and thickness | 11.32 × 0.56 | 11.32 × 0.56 | 14.20 × 0.555 | 14.20 × 0.555 |
| Plates, sectional orea, gross | 6.339 | 6.339 | 7.881 | 6.881 |
| Stress total | lbs. tons. 288,130 = 128.6 | lbs. tons. 292,810 = 230.7 | lbs. tons. 227,290 = 101.4 | lbs. tons. 229,410 = 102.4 |
| Stress for square inch of gross area, joint | 45,453 = 20.3 | 46,192 = 20.6 | 28,920 = 12.9 | 29,109 = 13.0 |
| Stress per square inch of plates, solid | 67,940 = 30.3 | 67,280 = 30.0 | 65,002 = 29.0 | 64,900 = 29.0 |
| Ratio of joint to solid plate, percentage | 66.9 | 68.6 | 44.5 | 44.8 |
| | 67.75 | | 44.65 | |
| Where fractured | Plate at five rivet holes, and one rivet sheared. | Plate at four rivet holes, and two rivets sheared. | Five rivets sheared. | Five rivets sheared. |
| Rivets: diameter, area and number | Steel 0.81 = 0.515 6×2 | Steel 0.81 × 0.515 × 6×2 | Steel 1.04 = 0.849 × 5×1 | Steel 1.04 = 0.849 × 5×1 |
| Rivets: sectional area, total square inches | 6.180 | 6.180 | 4.245 | 4.245 |
| Shearing stress per square inch of rivet area | 46,623 = 20.8 | 47,338 = 21.1 | 53,543 = 23.9 | 54,042 = 24.1 |
| Tensile stress per square inch of rivet area } Ratio of shearing to tensile, percentage } | Rivets were not sent for ascertaining the tensile strength and quality. | | | |

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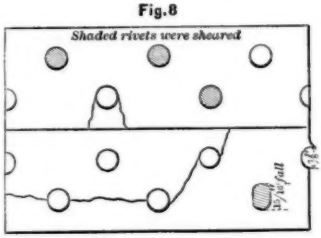
fracture=9.2 inches; area of fracture= $9.2\times0.545=5$ square inches; shearing strain of one rivet=25.34 tons; leaving 144.3−25.34=118.96 tons to break 5 square inches of plate; hence, strength of plate per square inch of fracture = $\frac{118.96}{5}=23.79$ tons $=\frac{23.79}{30}=0.793$ of solid plate; ratio of strength of joint of solid plate=66.7 per cent. This joint is remarkable, because the second half was nearly broken through at the same time that the first half gave way altogether.

Fig. 8




3. Joints G and H, with holes punched $\frac{5}{8}$ inch, and drilled out to $\frac{3}{4}$ inch in diameter.

G broke with 114.3 tons, by shearing two rivets and breaking along a line of fracture=4.82 inches; area of fracture $=4.82\times0.54=2.6$ square inches; sheared area of two rivets $=4\times0.441=1.764$ square inch; shearing strain of ditto= $1.764\times24.6=43.4$ tons; leaving 114.3−43.4 = 70.9 tons to break 2.8 square inches of plate; hence, strength of plate per square inch of fracture $=\frac{70.9}{2.6}=27.27$ tons $=\frac{27.27}{30.8}=0.885$ of solid plate; ratio of strength of joint to solid plate=61.02 per cent., as per report No. 1.

But the four half-rivets were again displaced sideway, and the holes elongated, as in joint D. The measurement of the elongated holes, after testing, was: half-hole on left $\frac{3}{4}\frac{1}{2}$ inch (half-rivet nearly sheared); half-hole on right $\frac{1}{4}$ inch; hole in which the rivet was sheared on left $\frac{1}{8}$ inch bare, and on right 1 inch full, as shown in Fig. 9.

H broke with 142.8 tons, by shearing two rivets and breaking along a line of fracture=7.47 inches; area of fracture $=7.47\times0.545=4.07$ square inches; shearing strain of two rivets=43.4 tons; leaving 142.8−43.4=99.4 tons to break 4.07 inches of plate; hence, strength of plate per square inch of fracture$=\frac{99.4}{4.07}=24.42$ tons $=\frac{24.42}{30.6}=0.798$ of solid plate; ratio of strength of joint to solid plate=64.71 per cent.

Before drawing any conclusions it appeared desirable to try the effect of drilling the holes in the joint-plates out of the solid, the covers being punched as before.

Two joints, K and L, were therefore prepared in this way, the arrangement of rivets being the same as before. A further difference was also introduced in the form of the specimens, which were shaped as in Fig. 7 (Report No. 4). The holes were drilled $1\frac{3}{16}$ inch in diameter. The pressure used in riveting was 35 tons, as before.

K broke with 128.6 tons, by shearing one rivet and breaking along a line of fracture=7.3 inches; area of fracture $=7.3\times0.56=4.09$ square inches; shearing strain of one rivet=25.34 tons, as in D; leaving 128.6−25.34=103.26 tons to break 4.09 square inches of plate; hence, strength of plate per square inch of fracture $=\frac{103.26}{4.09}=25.25$ tons $=\frac{25.25}{30.3}=0.833$ of solid plate; ratio of strength of joint to solid plate=66.9 per cent.

L broke with 130.7 tons, by shearing two rivets and breaking along a line of fracture=5.55 inches; area of fracture= $5.55\times0.56=3.1$ square inches; shearing strain of two rivets=50.68 tons; leaving 130.7 − 50.68 = 80.02 tons to break 3.1 square inches of plate; hence, strength of plate per square inch of fracture $=\frac{80.02}{3.1}=25.81$ tons $=\frac{25.81}{30}=0.86$ of solid plate; ratio of strength of joint to solid plate=68.6 per cent.

The results may now be considered with reference to—

I. The effect of the form of the specimen.
II. The effect of the mode of making the holes.
III. The general arrangement or proportions of the joint.

1. The effect of the form of the specimen may be judged by a comparison of A, D and G, Fig. 5, with B, E, H, Fig. 4, as shown in the following table:

| Mark of joint..... | A | D | G | B | E | H |
|---|---|---|---|---|---|---|
| Breaking-strain of section per square inch in tons..... | 23.5 | 25.23 | 27.27 | 23.00 | 23.79 | 24.42 |
| Ratio of same to that of solid plate.... | 0.778 | 0.838 | 0.885 | 0.774 | 0.793 | 0.798 |
| Ratio of strength of joint to that of solid plate, per cent..... | 64.19 | 63.83 | 61.02 | 63.13 | 66.70 | 64.71 |

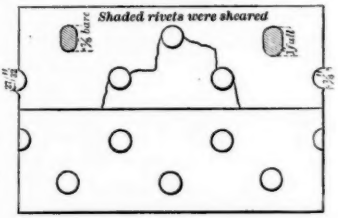
Comparing joints A and B, which not only were riveted, but also broke in the same way, namely, through the rivet-holes only, it will be seen that the strength per square inch of the plate, along the line of fracture, as well as the ratio of this strength to that of the solid plate, were practically identical in both cases. The ratio of the strength of the joint is slightly greater in A than in B, but the difference is not greater than may fairly be expected between similar test pieces. But as a correction has to be applied to the direct result obtained from B, it is fair to infer that the form of A gives a more reliable result than the form of B.

D and E, which were riveted in the same way, give more discordant results. As regards the strength of the section and the ratio of this to that of the solid plate, E compares very well with B and A. The ratio of strength of the joint is, however, different. In D the strength of the solid plate (30.1 tons per square inch) was practically the same as in E (30 tons per square inch), but the strength of the plate along the line of fracture appears to be 0.838 of that of the solid plate in D, compared with the ratios 0.778, 0.774, and 0.793 in A, B and E. The line of fracture in D passes behind the half-rivet on the left side, and to the inside of the one on the right side of the joint (Fig. 8). It is clear that the right-hand half-rivet must have been forced out of place, so as to allow the parts of the broken plate to separate, by part of the strain applied to break the joint; but as the half-rivet was not sheared, it is impossible to say how much strain it bore, though this must, of course, have been less than the strain that would have sheared it.

Whatever the amount of this strain, it is all credited to the section of the line of fracture, and hence the apparent increased strength of the plate in the joint and its ratio to the solid plate, given in the table. But, by whatever amount the strain sustained by the right-hand half-rivet fell short of its full shearing strain, by that same amount was the total proper breaking strain of the specimen joint reduced; hence the ratio of the strength of the joint also appears to be less than it really is. It seems, therefore, that the form of E gives as reliable results, in regard to the strength of the fractured plate and its ratio to the solid plate, as A and B did; but that the form D does not give reliable results.

Lastly, take G and H, which were again riveted in a similar manner. The plate in H was slightly stronger than the previous ones, but the ratio of its strength to that of the solid plate was nearly the same as in E. In short, H compares very well with A, B and E. In G the line of fracture passed inside both the half-rivets (Fig. 9), and the remarks made in refer-

Fig. 9




ence to the right-hand half-rivet in D apply to both half-rivets in this joint; the more so as the left-hand one was nearly sheared. The effect would therefore be greater than in D. Accordingly, the strength of the plate in the joint end its ratio to the strength of the solid plate is still more increased than in D, whilst the ratio of strength of the joint is further diminished.

The conclusions drawn are:

1. When none of the rivets are sheared,

and fracture takes place through all the rivet holes, the specimens, shaped through the centers of the rivets, give the most accurate result.

2. When rivets are sheared at the same time that fracture takes place, the specimens, shaped along a line between the rivets give, the most accurate results.

3. The correct way of estimating the strength of the joint is, to compute it from the strength of the plate along the line of fracture, as obtained from the tests.

4. The best way of getting a direct result would be to have two sets of joints prepared, one set being one pitch wider than the other set. The difference between the mean breaking-strain of these two sets of joints would at once give the breaking-strain for one pitch, which is what is wanted.

II. The effect of the mode of forming the holes.

The holes were formed in four different ways, as already stated.

1. By punching with a punch $\frac{13}{16}$ inch in diameter, as in A and B.

2. By punching with a $\frac{5}{8}$-inch punch and drilling out to $\frac{13}{16}$ inch in diameter, as in D and E.

3. By punching with a $\frac{5}{8}$-inch punch and drilling out to $\frac{3}{4}$ inch in diameter, as in G and H.

4. By drilling $\frac{13}{16}$ inch in diameter out of the solid, as in K and L.

As the results obtained from D and G are not reliable, for reasons already stated, they are not used in the present comparison.

The mean results from A and B, and K and L, and also those from E and H separately, are shown in the following table:

| Marks of joints | A and B | E | H | K and L |
|---|---|---|---|---|
| Breaking-strain of section in tons per square inch | 23.25 | 23.79 | 24.42 | 25.53 |
| Ratio of same to that of solid plate | 0.776 | 0.793 | 0.798 | 0.846 |

It is unfortunate that only one specimen of each of the classes 2 and 3, with punched holes, drilled out, can be used; the more so as it seems rather anomalous that H, with the holes drilled only to $\frac{3}{4}$-inch in diameter, so as barely to remove the punched surface, gives a slightly better result than E, in which the holes were drilled out to $\frac{13}{16}$ inch in diameter, and the punched surface was well cleared out. No comparison can be instituted between E and H, but they are so nearly alike that they may be classed together, and the mean ratio of 0.795 may be taken for the strength of the plate in the joint, as compared with the solid plate in both cases.

Thus the ratio of the strength per square inch of the plate along the line of fracture, compared with the strength of the solid plate, is:

| | | |
|---|---|---|
| 1. | For punched holes | 0.776 |
| 2 & 3. | " holes punched small and drilled out | 0.795 |
| 4. | " holes drilled out of the solid. | 0.846 |

It appears that little is gained over the ordinary punching, by punching the holes small and drilling them out larger; but by drilling the holes out of the solid the strength of the plate is increased 9 per cent., as compared with the punched holes.

III. The general arrangement or proportions of the joint.

For the purposes of this comparison, it is assumed that the fracture takes place along the zigzag line. The strength of the joints is then computed, from the data of the experiments, as follows:

Multiply the net length of the line of fracture, per pitch, by the breaking-strength per square inch of the metal in the joint, and by 100, and divide the product by the length of the pitch multiplied into the breaking-strength per square inch of the solid plate; the quotient is the strength of the joint in a percentage of the strength of the solid plate.

Omitting D and G as unreliable, the following results are thus obtained:

| | Strength of joint. per cent. |
|---|---|
| Mean of A and B—holes punched $\frac{13}{16}$-inch | 63.23 |
| E, holes punched $\frac{5}{8}$-inch, and drilled out to $\frac{13}{16}$-inch | 67.12 |
| H, holes punched $\frac{5}{8}$-inch, and drilled out to $\frac{3}{4}$-inch | 70.18 |
| Mean of K and L—holes drilled $\frac{13}{16}$-inch | 71.67 |

These results are not quite the same as those previously obtained, because they are computed for a supposed uniform line of fracture, as stated. It will be seen that the drilled holes in K and L give an excess of strength of more than 13 per cent. over the punched holes in A and B, but do not give much excess of strength over the punched and drilled holes in E and H. The strength of the weakest of these joints was sufficient for the purpose in this particular case; but even the strongest of them was not satisfactory, as it should certainly be 75 per cent. of the solid plate. It is clear that the rivets were stronger than the plate, although calculation shows that when the diameter was reduced to $\frac{3}{4}$ inch, as in G and H, the shearing strength of the rivets was nearly the same as the tensile strength of the plate in the joint.

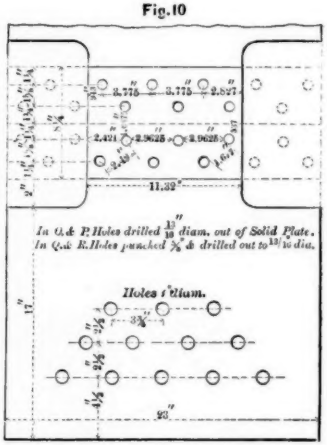
By increasing the pitch of the full-sized rivets, the joint would be strengthened, but $3\frac{3}{4}$ inches pitch is quite wide enough for $\frac{9}{16}$-inch plates to ensure tightness. If D and E be excepted, as the fracture in these two joints went past the rivet holes instead of through them, all the joints broke along the zigzag line, or from the rivet-holes to the edge of the plate. This was probably due to the rows of rivets being too close together, as well as too near the edge, and also to the pressure used in riveting having been too great.

To settle this point it was determined to have four more joints tested, two with $\frac{13}{16}$ inch drilled holes (O and P), to be 75 per cent. of the strength of the solid plate, and two (Q and R) of the same proportions, but with holes punched $\frac{5}{8}$ inch and drilled out to $\frac{13}{16}$ inch in diameter. All the joints were made from similar plates and rivets to those previously tried, but the accumulator-pressure was reduced to 25 tons. The pitch was 3.775 inches as before, and the breaking-strength of the solid plate 30 tons per square inch. Then for 75 per cent. strength of joint the breaking-strain per pitch should be $3.775 \times 0.75 \times \frac{9}{16} \times 30 = 47.78$ tons. For a shearing strength of rivets = 24.5 tons per square inch, the area of each rivet $= \frac{47.78}{4 \times 24.5} = 0.49$ square inch, so that $\frac{13}{16}$-inch diameter, giving a shearing area of 0.5185 square inch, will do for the rivets.

As not one fracture occurred from hole to hole along the straight line, the strength of the plate is assumed to be sufficient in that direction. Taking the strength along the zigzag line to be 0.85 of that of the solid plate, the net length between the holes should be $\frac{3.775 \times 0.75}{0.85}$ = 3.33 inches, and this would be obtained by a distance between the rows of the centers of the rivets of 1.606 inch. This distance was made $1\frac{5}{8}$ inch, so that the net length of zigzag line of fracture was 3.354 inches per pitch. The distance from the center of the holes to the edge of the plate was increased from $1\frac{1}{8}$ inch to $1\frac{1}{4}$ inch.

This joint is shown in Fig. 10, and the result of the tests given in report No. 6, whilst the tensile tests of the rivets are stated in report No. 7.

Fig. 10




The calculated strength of joint with $\frac{13}{16}$-inch drilled holes is $\frac{3.354 \times 0.85 \times 100}{3.775}$ = 75.52 per cent. of the solid plate.

REPORT No. 5.—Summary of the Results of Experiments to Ascertain the Elastic and Ultimate Tensile Strength and Quality of the Steel in Four Riveted Joints received from Messrs. Easton and Anderson.

Plates—all cut Lengthway.

| Specimens out of Riveted Joints. | Test No. | Thickness. | Stress. Elastic per Square Inch. | Stress. Ultimate per Square Inch. | Ratio of Elastic to Ultimate. | Contraction of Area at Fracture. | Stress Per Square Inch of Fractured Area. | Extension-set in 10 inches. At 50,000 lbs. per Sq. Inch. | Extension-set in 10 inches. At 60,000 lbs. per Sq. Inch. | Extension-set in 10 inches. Ultimate. | Appearance of Fracture. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | P. | Inch. | Lbs. Tons. | Lbs. Tons. | % | % | Lbs. | % | % | % | |
| P 2,945. K | 2,946 | 0.57 | 35,700 | 68,405 | 52.1 | 44.5 | 123,389 | 3 71 | 7.61 | 26.6 | Silky |
| | 2,947 | 0.55 | 35,500 | 67,475 | 52.6 | 45.7 | 124,326 | 3.55 | 8.40 | 26.8 | " |
| | Mean..... | | 35,600=15.9 | 67,940=30.3 | 52 3 | 45.1 | 123,857 | 3.63 | 8.00 | 26.7 | |
| P 2,948. L | 2,949 | 0.57 | 35,600 | 68,140 | 52.2 | 41 0 | 115,595 | 3.52 | 7.39 | 25.5 | " |
| | 2,950 | 0.55 | 35,600 | 66,420 | 53.6 | 48.1 | 128,179 | 3.88 | 9.08 | 27.1 | " |
| | Mean..... | | 35,600=15.9 | 67,280=30.0 | 52.9 | 44.5 | 121,887 | 3.70 | 8.23 | 26.3 | |
| P 2,951. M | 2,953 | 0.55 | 31,800 | 65,445 | 48 5 | 49.1 | 128,783 | 4.48 | 9.80 | 29.4 | " |
| | 2,952 | 0.56 | 31,800 | 64,560 | 49.2 | 47.4 | 122,762 | 4.46 | 11.10 | 29.6 | " |
| | Mean..... | | 31,800=14.2 | 65,002=29.0 | 48.8 | 48.2 | 125,772 | 4.47 | 10.45 | 29.5 | |
| P 2,954. N | 2,956 | 0.55 | 32,600 | 65,110 | 50.0 | 34.3 | 99,198 | 4.03 | 9.20 | 26.5 | " |
| | 2,955 | 0.56 | 32,400 | 64,690 | 50.0 | 46.6 | 121,361 | 4.55 | 11.10 | 29.3 | " |
| | Mean..... | | 32,500=14.5 | 64,900=29.0 | 50.0 | 40.4 | 110,279 | 4.29 | 10.15 | 27.9 | |
| | Total Mean. | | 33,875=15.1 | 66,280=29.6 | 51.0 | 44.5 | 120,448 | 4.02 | 9.21 | 27.6 | |

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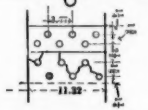
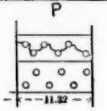
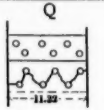
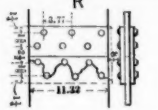
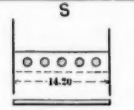
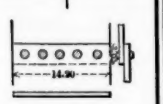
The tensile strength of the rivets in report No. 7—varying from 31.45 to 38 tons per square inch—shows such irregularity, and is so much in excess of the former tests (the rivets being taken from the same lot), that it cannot be accepted as trustworthy. The shearing strength of the rivets will therefore be taken as before, at 24.6 tons per square inch.

O broke with 133.6 tons, by shearing one rivet and breaking aloug a line of fracture=7.8 inches; area of fracture= $7.8 \times 0.555 = 4.33$ square inches. The strain that sheared one rivet was $24.6 \times 2 \times 0.515 = 25.34$ tons, leaving $133.6 - 25.34 = 108.26$ tons to break 4.33 square inches of plate; hence, strength of plate per square inch area of fracture $= \frac{108.26}{4.33}$ $= 25$ tons $= \frac{25}{29.6} = 0.845$ of solid plate.

The strength of this joint is given at 72 per cent. in report No. 6; but computing it in the manner already explained, the strength becomes $\frac{3.354}{3.775} \times 84.5 = 75$ per cent. If this joint had broken along the zigzag line throughout, like the next one P, the line of fracture for the pitch in which the rivet was sheared would have been 3.354 inches long, requiring a strain of $3.354 \times 0.555 \times 25 = 46.5$ tons to break it; whereas that pitch is here credited with a breaking-strain for the plate of $1.6875 \times 0.555 \times 25 = 23.4$ tons, and for the rivet of 25.34 tons, or a total strain=48.74 tons.

It is, therefore, fair to conclude that the rivet offered less resistance to shearing than has been assumed, and, consequently, that the strength of the plate along the line of fracture, as also the computed strength of the joint, was greater than given. But, considering the uncertainty of this conclnsion, and the fact that the strength of the fellow-joint

**REPORT No. 6.—Results of Experiments to Ascertain the Ultimate Tensile Strength of Six Riveted Joints received from Messrs. Easton and Anderson. All Steel Plates. Nominal thickness, nine-sixteenths of an inch.**

| Sketches of Joint with Sizes | O  | P  | Q  | R  | S  | T  |
|---|---|---|---|---|---|---|
| Test No. and thickness..... | P 4035 $\frac{9}{16}$ inch. | P 4038 $\frac{9}{16}$ inch. | P 4041 $\frac{9}{16}$ inch. | P 4044 $\frac{9}{16}$ inch. | P 4047 $\frac{9}{16}$ inch. | P 4050 $\frac{9}{16}$ inch. |
| Description of joint..... | Butt, double-riveted. | Butt, double riveted, | Butt, double-riveted. | Butt, double-riveted, | Lap, single-riveted. | Lap, single-riveted. |
| Machine or hand-riveted.... | Machine. | Machine. | Machine. | Machine. | Machine. | Machine. |
| Rivet holes..... | "Plates drilled, covers punched $\frac{13}{16}$." | "Plate drilled, covers punched $\frac{13}{16}$." | "Punched $\frac{5}{8}$ and bored $\frac{13}{16}$" | "Punched $\frac{5}{8}$ and bored $\frac{13}{16}$" | "Punched 1." | Punched 1." |
| Plates, width and thickness. | 11.32 × 0 555 | 11.32 × 0.54 | 11.32 × 0.535 | 11.32 = 0.555 | 14.20 × 0.555 | 14.20 × 0.555 |
| Plates, sect. area, gross.... | 6.282 | 6.112 | 6.056 | 6.282 | 7.881 | 7.881 |
| | lbs. tons. | lbs tons. | lbs. tons. | lbs. tons. | lbs. tons. | lbs. tons. |
| Stress total..... | 299,310 = 133.6 | 287,480 = 128.3 | 277,880 = 124.0 | 313,240 = 139.8 | 221,190 = 98.7 | 221,840 = 99.0 |
| Stress per square inch of gross area, joint. | 47,646 = 21.2 | 47,035 = 21.0 | 45,885 = 20.5 | 49,863 = 22.5 | 28,320 = 12.6 | 28,404 = 12.7 |
| Stress per square inch of plates solid. | 66,197 = 29.6 | 63,257 = 28.2 | 63.562 = 28.3 | 69,587 = 31.1 | | |
| Ratio of joint to solid plate, percentage. | 72.0 | 74.3 | 72.2 | 71.6 | | |
| | 73.15 | | | 71.91 | | |
| Where fractured..... | Plate at 5 rivet holes and 1 rivet sheared, 100 per cent. silky. | Plate at 6 rivet holes, 100 per cent., silky. | Plate at 6 rivet holes, 100 per cent., silky. | Plate at 6 rivet holes, 100 per cent., silky. | Five rivets sheared. | Five rivets sheared. |
| Rivets: dia., area and number..... | Steel 0.81 = 0.515 × 6 × 2 | Steel 0.81 = 0.515 × 6 × 2 | Steel 0.81 = 0.515 × 6 × 2 | Steel 0.81 = 0.515 × 6 × 2 | Steel 1.04 = 0.849 × 5 × 1 | Steel 1.04 = 0.849 × 5 × 1 |
| Rivets: sectional area total square inches. | 6.180 | 6.180 | 6.180 | 6.180 | 4.245 | 4.245 |
| Shearing stress per sq. inch of rivet area. | 48,432 = 21.6 | 46,517 = 20.7 | 44,964 = 20.1 | 50,686 = 22.6 | 52,106 = 23.2 | 52,259 = 23.2 |
| Tensile stress per sq. inch of rivet area. | 78,505 = 35.1 | 78,505 = 35.1 | 78,505 = 35.1 | 78,505 = 35.1 | 63,365 = 28.3 | 63,365 = 28.3 |
| Ratio of shearing to tensile, percentage. | One rivet sheared. | Not sheared. | Not sheared. | Not sheared. | 82.2 | 82.4 |
| | | | | | 82.3 | |

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P is so much greater than that of K and L (which also had $\frac{1}{16}$ inch drilled holes), it seems preferable to adhere to the computed strength, and to use it together with the results of joint P, for comparison with other joints.

P broke with 128.3 tons, by shearing through the rivet-holes along a line of fracture=9.46 inches; area of fracture =9.46×0.54=5.1 square inches; strength of plate per square inch of fracture = $\frac{128.3}{5.1}$ =25.15 tons = $\frac{25.15}{28.2}$ =0.89 of solid plate.

The ratio of strength of joint given in report No. 6 is 74.3 per cent. But, computed from the strength of the plate in the joint as explained, it becomes $\frac{3.354}{3.775}$ ×89=79 per cent., or more than was expected.

Q broke with 124 tons through the rivet-holes, like P; length of fracture= 9.46 inches; area of fracture = 9.46 × 0.535=5.06 square inches; strength of plate per square inch of fracture = $\frac{124}{5.06}$= 24.5 tons = $\frac{24.5}{28.3}$=0.866 of solid plate.

The ratio of strength of joint in report No. 6 is 72.2 per cent. But, computed from the strength of the plate in joint, the ratio becomes $\frac{3.354}{3.775}$ × 86.6 = 76.9 per cent.

R broke with 139.8 tons through the rivet-holes, like Q and P; length of fracture=9.46 inches; area of fracture=9.46 ×0.555=5.25 square inches; strength of plate per square inch of fracture = $\frac{139.8}{5.25}$=26.63 tons = $\frac{26.63}{31.1}$=0.856 of solid plate.

The ratio of strength of joint in report No. 6 is 71.6 per cent. But, computed from the strength of the plate in the joint, the ratio becomes $\frac{3.354}{3.775}$ × 85.6 =76 per cent.

The following table gives the results for comparison of the means of K and L with O and P; and E with Q and R:

| Marks of joints | K and L | O and P | E | Q and R |
|---|---|---|---|---|
| Ratio of strength of metal in joint to solid plate | 0.846 | 0.867 | 0.793 | 0.861 |
| Computed ratio of strength of joint per cent. | 71.67 | 77.0 | 67.1 | 76.45 |

Thus the widening of the distance between the rows of rivets and between the rivets and the edge of the joints resulted in 7·57 per cent. increase of strength of the joint in the case of the drilled holes (K, L, and O, P), and 13.9 per cent. in the case of the punched holes (E and Q, R) drilled out; whilst the drilled holes in O and P show an advantage of only 0·85 per cent. over the punched and drilled holes in Q and R.

In every case the metal in the joint is weaker than in the solid plate; and this reduction of strength is least with the holes drilled out of the solid, and greatest with the punched holes. This result has very generally been obtained by most experimenters. Possibly the diminished pressure in the accumulator for riveting the four last joints, O, P, Q, and R, may have contributed to reduce the weaking of the metal in the joint; but as the experiments do not supply any data for considering this point it cannot be noticed here, except to suggest that, if the pressure is too great for the diameter of rivet, thickness of plate, and number of plates riveted, the metal round the holes may be injured and the strength of the joint weakened. This is a point that appears worthy of special investigation.

Whatever the true explanation may be of the diminution of strength of the metal in the joint, it is clear that the presence of the holes in the plate must somehow produce this result.

Supposing that the metal round the hole is not competent to bear the full strain due to its section, it may be assumed, without appreciable practical error, that a zone of metal round the whole does no work at all, and the rest of the section of the plate bears the full breaking-strain of the solid plate.

REPORT No. 7.—SUMMARY OF THE RESULTS OF THE EXPERIMENTS TO ASCERTAIN THE JOINTS AND EIGHT RIVETS RECEIVED

Plates—all cut Lengthway.

| Specimens out of Riveted Joint. | Test No. | Thickness. | Stress. Elastic per Square Inch. | Stress. Ultimate per Square Inch. | Ratio of Elastic to Ultimate. | Contract of Area at Fracture. | Stress per Square Inch of fractured Area. | Extension-set in 10 Inches. At 50,000 lbs. per Square Inch. | Extension-set in 10 Inches. At 60,000 lbs. per Square Inch. | Extension-set in 10 Inches. Ultimate. | Appearance of Fracture. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | P. | In. | Lbs. Tons. | Lbs. Tons. | % | % | Lbs. | % | % | % | |
| P 4,035. | 4,036 | .56 | 36,500 | 66,655 | 54.7 | 51.4 | 13 7231 | 3.49 | 7.79 | 28.5 | Silky |
| O & P | 4,037 | .55 | 35,600 | 65,740 | 54.1 | 53.5 | 141,514 | 4.11 | 9.39 | 29.8 | " |
| | Mean.... | | 36,050=16.1 | 66,197=29.6 | 54.4 | 52.4 | 139,372 | 3.80 | 8.58 | 29.8 | |
| P 4,038. | 4,039 | .54 | 33,700 | 63,310 | 53.2 | 52.0 | 131,998 | 5 35 | 12.8 | 28.6 | " |
| O & P | 4,040 | .54 | 33,700 | 63,205 | 53.3 | 53.0 | 134,637 | 5.54 | 12 5 | 27.8 | " |
| | Mean.... | | 33,700=15.0 | 63,257=28.2 | 53.2 | 52.5 | 133,317 | 5.44 | 12·8 | 28.2 | |
| P 4,041. | 4,042 | .52 | 33,800 | 63,710 | 53.0 | 52.5 | 134,397 | 4.66 | 11.1 | 31.2 | " |
| Q & R | 4,043 | .53 | 33,800 | 63,415 | 53.3 | 52.0 | 132,323 | 4.81 | 11.3 | 30.4 | " |
| | Mean.... | | 33,800=15.1 | 63,562=28.3 | 53.1 | 52.2 | 133,359 | 4.73 | 11.2 | 30.8 | |
| P 4,044. | 4,046 | .55 | 39,200 | 69,720 | 56.2 | 52.9 | 148,054 | 2.08 | 5.61 | 27.5 | " |
| Q & R | 4,045 | .56 | 39,500 | 69,455 | 56 8 | 52.1 | 147,369 | 1.59 | 5.19 | 25.9 | " |
| | Mean.... | | 39,350=17.6 | 69,587=31.1 | 56.5 | 52.5 | 147,711 | 1.83 | 5.40 | 26.7 | |
| | Total Mean | | 25,725=15.9 | 65,651=29.3 | 54.3 | 52.4 | 138,439 | 3.95 | 9.49 | 28.7 | |

Let $d$ = diameter of the hole.

$d_1$ = " " inoperative zone of metal.

$p$ = distance from center to center of the holes diagonally.

$f$ = ratio of the strength of metal in the joint to the solid plate.

Then $(p-d)\times f = p-d_1$, and $d_1 = p-(p-d)\times f$.

inch.

For K and L $d_1 = 2.41 - 1.5975 \times 0.846 = 1.060$ and $d_1 - d = 0.2475$

" O " P " $= 2.49 - 1.6770 \times 0.867 = 1.036$ and $d_1 - d = 0.2235$

inch.

For E and $d_1 = 2.41 - 1.5975 \times 0.793 = 1.143$ and $d_1 - d = 0.3305$

" Q " R " $= 2.49 - 1.6770 \times 0.861 = 1.046$ and $d_1 - d = 0.2335$

" A " B " $= 2.41 - 1.5400 \times 0.776 = 1.215$ and $d_1 - d = 0.3450$

" H " $= 2.41 - 1.6600 \times 0.798 = 1.085$ and $d_1 - d = 0.3350$

If this view is correct, the net effective section thus obtained should, for the joints tested, be greater along the straight line than along the zigzag line, as none of them broke along the straight line. The net effective length of plate per pitch is thus:

ELASTIC AND ULTIMATE TENSILE STRENGTH AND QUALITY OF THE STEEL IN FOUR RIVETED FROM MESSRS. EASTON AND ANDERSON.

Steel Rivets.

| Nominal Size of Rivets. | Test No. | Original Diar. | Original Area. | Stress. Elastic per Square Inch. | Stress. Ultimate per Square Inch. | Ratio of Elastic to Ultimate. | Fractured. Dia. | Fractured. Area. | Fractured. Difference. Area. | Fractured. Difference. Per cent. | Stress for Square Inch of fractured Area. | Extension. | Appearance of Fracture. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P. | In. trnd | Sq. In. | Lbs. Tons. | Lbs. Tons. | % | In. | Sq. In. | | | | To short for ascertaining the Extension. | |
| ¾ in. dia. | 4,055 | .504 | .200 | 47,300 | 85,130 | 55.5 | .36 | .102 | .098 | 49.0 | 166,921 | | Silky. |
| ¾ in. dia. | 4,053 | .504 | .200 | 47,100 | 84,810 | 55.5 | 35 | .096 | .104 | 52.0 | 176,687 | | " |
| " | 4,054 | .504 | .200 | 44,400 | 73,620 | 60.3 | .32 | .080 | .120 | 60.0 | 184,050 | | " |
| " | 4,056 | 504 | 200 | 42,200 | 70,460 | 59.8 | .30 | .071 | .129 | 64.5 | 198,478 | | " |
| | Mean | | | 46,550=20.1 | 78,505=35.1 | 57.8 | | | | 56.4 | 181.534 | | |
| 1 in. dia. | 4,057 | .714 | .400 | 34,700 | 65,740 | 52.7 | .45 | .159 | .241 | 60.2 | 165,383 | | " |
| 1 in. dia. | 4,059 | .714 | .400 | 34,600 | 64,110 | 53.9 | .45 | .159 | .241 | 60.2 | 161,283 | | " |
| " | 4,060 | .714 | 400 | 34,200 | 62,330 | 43.8 | .44 | .153 | .248 | 62.0 | 164,026 | | " |
| " | 4,058 | .714 | .400 | 34,100 | 61,280 | 55.6 | .44 | .153 | .248 | 62.0 | 161,263 | | " |
| | Mean | | | 34,409=15.3 | 63,365=28.2 | 54.2 | | | | 61.1 | 162,980 | | |

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inches.

For K and L, along the straight line 2.715
along zigzag 2.700

" O " P, along the straight line 2.739
along zigzag 2.900

" E along the straight line 2.632
along zigzag 2.534

" Q " R, along the straight line 2.729
along zigzag 2.888

" A " B, along the straight line 2.560
along zigzag 2.390

" H along the straight line 2.690
along zigzag 2.650

At first sight these results do not bear out the supposition of an inoperative zone of metal round the hole, as in two cases, namely O and P and Q and R, the zigzag length is greater than the straight one. But these joints were made with an increased distance between the rows of rivets; and it seems fair to infer that the metal along the zigzag line is weaker than that along the straight line. More experiments should be made to clear up these two points.

Meanwhile, as regards the proportions of the joints experimented on, with a pitch of 3·775 inches, the distance between the rows of rivets might probably be increased to $1\frac{3}{4}$ inch, with a slight addition of strength to the joint.

The ratios of strength are summarized in the following table:

| Description of Joints. | | Ratio of Strength of Plate in Joint to Solid Plate. | Ratio of Strength of Joint to Solid Plate. |
|---|---|---|---|
| | | | Per cent |
| 1½ inch between rows of rivets, and 1¼ inch from center of rivet to edge. | A and B with holes punched $\frac{7}{16}$-in. in diameter. | 0.776 | 63.23 |
| | E with holes punched ⅝-inch and drilled out to $\frac{11}{16}$-inch in diameter. | 0.793 | 77.12 |
| | H with holes punched ⅝-inch and drilled out to ¾-inch in diameter. | 0.798 | 70.18 |
| | K and L with holes drilled $\frac{13}{16}$-in. in diameter. | 0.846 | 71.67 |
| 1⅝ inch between rows of rivets, and 1¼ inch from center of rivet to edge. | O and P with holes drilled $\frac{13}{16}$-inch in diameter. | 0.867 | 77.00 |
| | Q and R with holes punched ⅝-inch, and drilled out to $\frac{13}{16}$-inch in diameter. | 0.861 | 76.45 |

The obvious conclusion is that the punched holes make the weakest joint, and the drilled ones the strongest, whilst those with holes punched small and drilled out come between the two. Another conclusion is that widening the distance between the rows of rivets materially increased the strength of the joint. But there is yet a third conclusion of some importance, which appears to be justified by these results, namely, that increasing the distance between the rows of rivets reduces the difference in strength between the joints with drilled holes and those with holes punched small and drilled out.

Would a further increase of distance between the rows of holes practically abolish this difference in strength? And furthermore, would it increase the strength of the joint with punched holes so much as to make it little inferior to that with drilled holes? These are questions which require further experiments for their answer, and they appear to be well worthy of consideration. One point has still to be noticed in reference to these experiments, namely, the mode of attachment of the specimens to the machine. Figs. 4, 5, 6, 7, and 10, show how this was effected in each case. In joints B, E, H, A, D, G, ten 1-inch holes were used, namely, three in the first row, four in the second, and three in the third or back row. In all cases these holes were elongated by the test strain, the elongation being greatest in the first row, and rather less in each of the succeeding rows. It was also almost always greatest in the holes on or nearest the center line of the joint, diminishing to either side as the holes recede from the center line. The elongation of the front center hole varied from $\frac{1}{16}$ inch bare to $\frac{1}{16}$ inch full, whilst that of the holes in the back rows was only the difference between an easy and a tight fit of the callipers. Joints K, L, O, P, Q, and R, were each held by twelve 1-inch pins, two more being put in the back row than before, with the effect of diminishing the elongation of the holes, so that it was hardly perceptible in the back row. But again the elongation appeared to be greatest at the center of each row of holes. Joints C, F, and I, in which the rivets were sheared, were attached by four 1½ inch pins. The elongation of the holes was slight, rather more in the two middle holes than in the side ones. Thus in the joints B, E, H, A, D, G, with ten 1-inch holding pins disposed in three row, where the greatest elongation occurred, the bearing pressure under breaking strain varied from 20 to 26 tons per square inch. In the joints K, L, O, P, Q, R, with twelve 1-inch holding pins, disposed in three rows, when the elongation was less, the bearing pressure was 18 to 21 tons per square inch. And in the joints C, F, I, with four 1½ inch holding pins, all in one row, the bearing pressure was 20 tons per square inch, with hardly any elongation of the holes.

The last four tests of the series were with single-riveted lap joints, of the proportions of the circular seams in the boilers. The strength of the joint was evidently sufficient for the purpose, and it was not intended to test either this or

the strength of the plate in the joint. The object of the tests was twofold—first, to ascertain the shearing-strength of 1 inch rivets, and secondly to ascertain the effect on the same of the plates being curved transversely to the direction of the strain, which is the condition of these joints in boilers.

Two joints were made with the plates curved as in the boiler shell to a diameter of 10 feet 3 inches, and marked M and N, Fig 11; and two others, exactly the same in all other respects, were left flat, and marked S and T, Fig 12. The particulars of the tests of these joints are given in Reports Nos. 4 and 6, and those of the plates and rivets in Reports Nos. 5 and 7.

The diameter of the rivets was 1 inch nominal, the pitch 2.84 inches, and the lap 3 inches nominal. The holes were punched and the joints riveted with an accumulator pressure of 35 tons.

The results were as follows:

| | Curved. | | Flat. | |
|---|---|---|---|---|
| Mark of joints..... | M | N | S | T |
| Total breaking strains in tons..... | 101.4 | 102.4 | 98.7 | 99.0 |
| Shearing strain of rivets, tons per square inch..... | 23.9 | 24.1 | 23.25 | 23.32 |
| Mean tensile strength of rivets, tons per square inch..... | 28.3 | 28.3 | 28.3 | 28.3 |
| Ratio of shearing to tensile strains..... | 0.843 | 0.852 | 0.822 | 0.824 |

In each case the plate was bent in the usual way, in the width of the lap, from the straight line, as shown in Figs. 11 and 12, namely, in M $\frac{3}{8}$ inch bare, in N $\frac{7}{16}$ inch bare, in S $\frac{3}{8}$ inch, and in T $\frac{7}{16}$ inch, or slightly more in the flat joints than in the curved ones. If the curved specimens had been wider no doubt this bending back would have been less, whilst in a complete circle it would have been very much less. The mean shearing strength of the rivets was: in the curved joints=24 tons per square inch= 0·848 of tensile strength; in the flat joints=23·28 tons per square inch= 0·823 of tensile strength. The mean result was the $\frac{3}{4}$-inch rivets in double shear was 24·6 tons per square inch= 0·857 of tensile strength.

Fig. 11

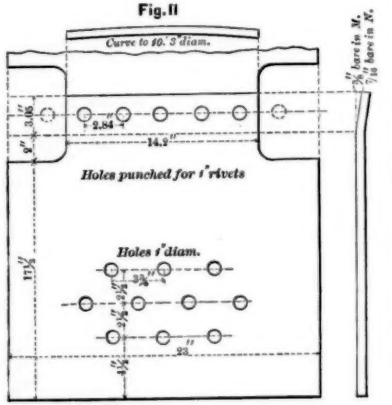
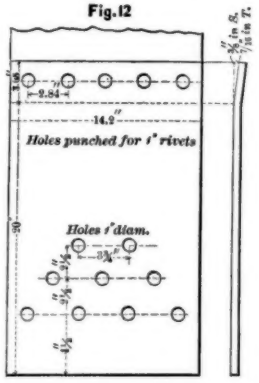



Fig. 12




The conclusions drawn are as follows:

1. The curved lap-joint is stronger

than the flat one, even in the comparatively narrow specimens tested. In a complete cylinder the excess of strength over a flat joint would probably be greater.

2. The 1-inch rivets are slightly weaker to resist shearing than the $\frac{3}{4}$-inch rivets; but probably this difference in strength would disappear in a complete circular joint, as the curved specimens give a greater strength than the flat ones.

3. Taking the tensile strength of rivets at 28 to 29 tons per square inch, it seems fair, for practical purposes, to assume the shearing strength to be 85 per cent. of the tensile strength for double-riveted, double-cover, butt-joints, and also for the complete circular lap-joints, and 82 per cent of the tensile strength for flat lap-joints.

In conclusion, the attachment of the four last joints to the machine has now to be noticed, as shown in Figs. 11 and 12.

Joints M and N were attached by ten 1-inch pins, and placed between curved blocks to retain the plates in shape. The elongation of the holes was hardly perceptible.

Joints S and T were attached by nine 1-inch pins, but with two pins only in the front row, and the elongation (though still very slight) was greater than in joints M and N, whilst the elongation of the holes in the front row was perceptibly greater than in the back row.

The bearing pressure of the pins on the plate at the breaking strain was $18\frac{1}{2}$ tons per square inch of surface for joints M and N with ten pins, and 20 tons per square inch for S and T with nine pins.

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## ELECTRICAL CONDUCTORS.

By Mr. W. H. PREECE, F.R.S., M.I.C.E.

From "Iron."

The first aerial conductors were made of copper, and the first gutta-percha-covered wires were of iron; but the positions were soon changed, copper being universally used for insulated conductors, and iron, until lately, for overhead lines. Sir William Thomson detected great variations in the quality of copper, and Matthiessen detected the causes, and established a standard of purity. Such improvements have been made in the quality, that copper wire was now twice as good as it was in 1856. Increased speed of working, improved efficiency of apparatus, and reduced waste of energy had followed the great increase in the purity of the copper. Temperature was a disturbing agent in the conductivity of the wire. Resistance increased more than 20 per cent. between winter and summer temperatures. Copper had recently been much used for aerial lines, it was less attacked by acids, and had great durability. Hard-drawn wire was now produced which had a breaking strain of 28 tons on the square inch, iron wire giving only 22 tons on the same area. Age did not seem to affect its quality, nor did it appear to be influenced by the currents of electricity employed for telegraphic purposes. The conductors of all cables remained constant. Lightning was supposed to render it brittle. The ultimate effect of the powerful currents employed for electric lighting was not yet known. The size of conductors was controlled by commercial considerations. Sir William Thomson had laid down the law that should control the size of leads for electric light, while that for cables followed strictly theoretical conditions. The best copper for electrical purposes came from Japan, Chili, Australia, and from Lake Superior; but much pure copper was obtained by electro-deposition, either directly from a solution,, or by using impure copper as the anode in a depositing bath. Electro-deposited copper had not the strength of ordinarily refined copper. The electrical resistance of commercial iron was from six to seven times that of copper, but its variation, due to the presence of impurities, was even greater. The weight of a

cylindrical wire one mile in length, and giving one ohm resistance at 60° Fahr., was called an ohm-mile. While the first iron wire was specified to give an ohm-mile of 5,500 lb., it was now obtained as low as 4,520 lb., and the maximum resistance was specified at 4,800 lb. The ordinary best puddled iron was at present used only for fencing purposes, but a mild English Bessemer steel was largely used for railway telegraphs and for stays; however, the resistance was very high, owing to the presence of manganese.

The wire used by the Post Office was made from Swedish charcoal iron, with an ohm-mile resistance of about 4,520 lb. Swedish Bessemer, or a specially prepared low-carbon English Bessemer, was adopted by the Indian Government, with an ohm-mile resistance of about 5,000 lb. Cast-steel wire, with a breaking weight of about 80 tons to the square inch, had been adopted on the Continent for telephone currents, with an ohm-mile resistance of 8,000 lb., while in England, where speed of working was the prime consideration, and length of span was negligible, electricians were satisfied with a breaking-strain of 22 tons on the square inch; in the colonies, where long spans were essential, and speed of working was not so important, the specification of 30 tons on the square inch. The electrical conductivity of iron wire increased with the percentage of pure iron, except where the percentage of manganese was high; an increase in the percentage of manganese augmented the electrical resistance considerably more than an increase in the percentage of sulphur or phosphorus. The durability of iron wire was maintained by galvanizing. When the galvanized wire was to be suspended in smoky districts it was additionally protected by a braided covering, well tarred. In some countries galvanizing was not resorted to, but dependence was placed on simple oiling with boiled linseed oil. Such a wire was erected in 1856 between London and Crewe, but the result was very unsatisfactory. More recently (1881) the experiment had been repeated with a similar result. In this climate galvanization was imperative. But it was not alone in smoky districts that iron wire decayed. It suffered much along the seashore. The salt spray decomposed the zinc oxide into soluble compounds, which were washed away and left the iron exposed, and this was speedily reduced to mere thin red lines. Where external decay was not evident time seemed to have no apparent effect on iron wire. Thirty-nine years of incessant service in conveying currents for telegraphy had not apparently altered the molecular structure of the iron wires in the open country on the London and South-Western Railway. Swedish charcoal iron was imported either in bloom or in rods, principally in rods. Each rod was rolled down to about 0.26 inch in diameter, and weighed on the average about 1 cwt. Iron wire could be rolled and drawn into coils 0.171 inch in diameter, weighing 400 lb. and measuring 1 mile; but 110 lb. was about the best practical limit for transport and use. The Swedish iron owed its value, not only to its comparative purity, but to the fact that it was smelted and puddled entirely with charcoal. The best qualities were a mixture of various ores, and they were known by various brands, the conditions determining those brands being secrets.

The operation of testing was a most important one, and requisite not only for the user, but also for the manufacturer. Flaws, impurities, faults, notwithstanding the greatest care, would occur, and they could be detected only by the most rigid examination and tests. Tests were mechanical and electrical. The mechanical tests embraced one for breaking strain, another for elongation, and a third for resistance to torsion. For hard steel wire, in place of the torsion test it was usual to specify that the wire should bear wrapping round its own diameter and unwrapping again without breaking. The electrical test was simply that for resistance—$\frac{1}{10}$ of a mile of the wire to be examined was wound round a dry wooden drum, and its electrical resistance was taken in ohms by means of a Wheatstone's bridge. Galvanization was tested by dipping in sulphate of copper, and by bending or rolling round a bar of varying diameter, according to the size of the wire. Special machines were constructed for the mechanical tests, the condition to be fulfilled being that for the breaking strain the increasing load or stress should be applied uniformly, without jerks or jumps, and the elongation machine should

correctly register the actual stretch without the wire slipping. The resistance to torsion of the wire was determined by an ink mark which formed a spiral on the wire during torsion, the number of spires indicating the number of twists taken before breaking. The perfection to which the manufacture of iron wire had been brought was very much due to the care bestowed upon the specifications by the authorities of the Post Office. The standard had been gradually raised, until it had attained a very high one. Many administrations objected to the expense of thorough inspection, with the result that they were the recipients of the rejected material of those who did rigidly inspect. One break in the wire cost far more than its inspection, and one extra ohm per mile affected the earning capacity of the wire in inverse proportion. It was, however, necessary to remark that the mechanical quality of charcoal-iron wire sometimes changed with time—its electrical quality remaining unaffected. Tests repeated at some subsequent period might therefore be deceptive unless allowance were made for the effect of time. Bessemer or homogeneous iron wire as a rule improved in its mechanical properties by being kept in stock. The Post Office authorities had decided to abandon a gauge altogether as applied to conductors, and to define size by diameter and weight. In future, all copper wires would be known by their diameters in "mils," or thousandths of an inch, and all iron wires by their weight in lb. per mile. Steel wire was used for long spans, or for places where great tensile strength was needed; but it was for the external strengthening of deep-sea cables that steel wire was principally adopted. It was first employed in the Atlantic cable of 1865 for this purpose. It had since been generally used for deep-sea cables. The usual diameter was 0.099 m., and it was specified to bear a breaking strain of 1,400 lb., which was equivalent to 81 tons on the square inch. Steel wire had been produced giving a much higher tensile strength. A compound wire of steel and copper was introduced in America about 1874, and it had been extensively tried in both hemispheres, but without success. Recently a compound wire had been erected between New York and Chicago, a distance of 1,000 miles, giving only 1.7 ohm resistance per mile. It had a steel core 0.125 inch in diameter, and was coated with copper electrolytically to a diameter of 0.25 inch. It weighed 700 lb. per mile. Hard-drawn copper, or silicious bronze of a much lighter character, would be equally efficient.

Phosphor-bronze, the hard mechanical qualities and great resisting powers of which were well known, was introduced for telegraph wire about five years ago. Several lengths were erected by the Post Office. Two long spans crossed the channel that separated the Mumbles Light house from the headland near Swansea. The object in view was to obtain great tensile strength with a power to resist oxidation, especially active where the wire was exposed to sea spray. This was done in 1879, and in November, 1883, not the slightest change was noticeable in the wire. But phosphor-bronze, though extensively used, had high electrical resistance; its conductivity was only 20 per cent. that of copper. Moreover, the phosphor-bronze supplied was irregular in dimensions and brittle in character. It would not bear bends or kinks. A new alloy, silicious bronze, had recently been introduced to remedy these disadvantages. Phosphor-bronze had disappeared for telegraph wire, and had been replaced by silicious bronze. The electric resistance of silicious bronze could be made nearly equal to that of copper, but its mechanical strength diminished as its conductivity increased. Wire, whose resistance equalled 90 per cent. of pure copper, gave a tensile strength of 28 tons on the square inch; but when its conductivity was 34 per cent of copper, its strength was 50 tons on the square inch. Its lightness, combined with its mechanical strength, its high conductivity and indestructibility, rendered it eminently adapted for telegraphs. If overhead wires were erected of such a material, upon sight supports, and with some method, there would be an end to the meaningless crusade now made in some quarters against aerial lines. These, if constructed judiciously, and under proper control, were far more efficient than underground lines. Corporations and local authorities should control the erection rather than force ad-

ministrations to needless expense and to reduced efficiency by putting them underground. Not only did light wires hold less snow and less wind, but they produced less electrical disturbance, they could be rendered noiseless, and they allowed existing supports to carry a much greater number of wires. German-silver was employed generally for rheostats, resistance-coils, and other parts of apparatus in which high resistance was required. It consisted of copper four parts, nickel two parts, and zinc one part. It possessed great permanence, and the variation in its resistance due to changes of temperature was small. The effect of age on German-silver was to make it brittle. Mr. Willoughby-Smith had found a smilar change with age even with wire drawn from an alloy of gold and silver. The form and character of electrical conductors must vary with the purposes for which they were intended. For submarine cables and for electric-light mains, where mechanical strength was not required, and where dimensions were of the utmost consequence, the conductors must be constructed of the purest copper producible, for copper was the best practical material at command. For aerial lines they must not only have great tensile strength, but in these days of high-speed apparatus they must have high conductivity, low electrostatic capacity, expose to wind and snow the least possible surface, and must be practically indestructible. Iron had hitherto occupied the field, but copper and alloys of copper seemed destined in many instances to supplant that metal, and to fulfill all the conditions required in a more efficient way, and at no greater cost per mile.

## REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS, November 21, 1883.

The Society met at 8 P.M., Director Geo. S. Greene, Jr., in the chair, John Bogart, Secretary.

A paper by E. H. Keating, M. Am. Soc. C. E., upon the Shubenacadie Canal, was read.

This canal is located between the City of Halifax, Nova Scotia, and the Basin of Mines, an arm of the Bay of Fundy. It was commenced in 1826, and the intention was to build it so as to accommodate vessels drawing 8 feet of water, with the idea that at comparatively small additional expense it could be used by vessels drawing 11 feet. It was to have 15 locks, 87 feet in length and 22 feet in width, with a lockage ascending from Halifax of 95 feet 10 inches, and descending to the Bay of Fundy of 95 feet 4 inches. The total length is about 54 miles, the greater portion of which was to be in the Shubenacadie River, and in a chain of lakes existing along the line of the canal.

Mr. Thomas Telford, the celebrated engineer, made a very favorable report upon the proposed canal and its prospects. Up to the close of 1831, £72,000 had been expended upon the work which was, however, in an entirely uncompleted state. Some of the locks near Halifax had not been commenced, and large and expensive work remained to be done upon the line of the canal. All the available capital being exhausted, the works were abandoned and fell into ruin, never having been completed on the original plan. In 1856, a report was made by Mr. W. H. Talcott, C. E., upon a scheme for completing the works upon a very much smaller scale than at first proposed, substituting for certain of the locks, an incline plane near Halifax, with a lift of 55 feet, and a similar plane with a lift of 33 feet at another point. The planes to be worked by hydraulic machinery. This report was adopted, and the work was completed in 1862, at a cost of $200,000. The diminished canal has, however, proved a failure as a commercial enterprise, and since 1870 no trade of any account has been carried on through it.

There was also presented a description, by Charles C. Smith, M. Am. Soc. C. E., of a hydraulic canal built at Minneapolis, Minn., during the severely cold winter of 1881. This canal is under Main Street, Minneapolis, its entrance being at right angles to the street. It is covered with a semi-circular rubble stone arch of 17½ feet span, and where the line turns the angle of 90° the abutments of the arch were built of curved lines of the radius of 31¼ and 48¾ feet. The arch was built of rubble masonry of stone varying from 4 to 6 inches thick, and from 18 to 36 inches long; the joints at the soffit being slightly hammered off to approximately form beds conforming to the radial lines of the arch. The mortar was made of one part Louisville cement to two parts of sand, and was mixed in hot water without salt. During its construction the weather was extremely cold, the frost having penetrated the ground to the depth of six feet.

An examination of this work having been made quite recently, it was found to be perfectly sound and free from any indication of settlement or rupture two years after its construction.

A discussion followed by the members present, more particularly in reference to the best methods of laying masonry in very cold weather, the experience of a number of members being favorable to the use of a strong solution of salt in the water with which the mortar was made.

The recent adoption of a system of time standards by the railways was discussed, and Prof. Julius E. Hilgard, M. Am. Soc. C. E., gave a statement as to the measures which were in progress in reference to securing a standard prime meridian, together with other measures

pertaining to the determination of standard time by the various nations of the world.

He also described the results of the recent meeting at Rome, Italy, of the Superintendents of the Geodetic Surveys of various nations.

ENGINEERS' CLUB OF PHILADELPHIA—RECORD OF REGULAR MEETING, NOVEMBER 17th, 1883.—Vice-President Wm. A. Ingham in the chair.

Mr. Edward I. H. Howell presented a sketch, based upon his personal observation while in England on a business visit, of the practice and peculiarities of the English machinists, with regard to machine tools.

He also exhibited specimens of polished shafting, from $1\frac{1}{8}''$ to $2\frac{3}{4}''$ in diameter, cold drawn, like wire, but omitted full description, as he expected the inventor to be present at a later meeting.

The Secretary read an illustrated paper by Mr. G. T. Gwilliam, upon the methods of making and placing the mattresses and fascines at the extension of the Delaware Breakwater Harbor.

The Secretary presented notes, by Mr. John J. Hoopes; to illustrate methods of eomputing tables by successive additions instead of separate calculations. Illustrations are given for the first, second, third and fourth powers, triangles and circles.

Mr. John Haug presented illustrated notes upon boiler construction, touching especially upon what should be shown in drawings and specifications for boilers.

Mr. George S. Strong exhibited specimens of cylindrical and corrugated flues. The former readily yielded to the pressure of the fingers, while the latter was trampled upon without injury.

The Secretary read, for Mr. C. J. Hexamer, a description of his experiments upon, with a discussion of the causes of, dust explosion in mills. Mr. William A. Ingham considered that some explosions in coal mines are probably attributable to the immense quantity of fine dust in the air, and Mr. T. Mellon Rogers, in response to Mr. Hexamer's comments upon the general absence of adjustable rolls in Philadelphia mills being a common cause of ignition, by the friction of foreign metallic particles in the stock, spoke of their general use in the West.

## ENGINEERING NOTES.

THE PANAMA CANAL.—According to a statement by M. Dingler, Director-General of the Panama Canal work, the amount of earthwork will be 100 millions, instead of 80 millions as previously estimated. These, however, it is now said, will cost less than 80 millions would have done had the rock expected been met with. It is now affirmed that the very hard rock does not exist, and even the hard rock is much less thick than a survey had indicated. The soil being thus much less refractory than was originally supposed, the mode of cutting has been changed. The embankments of the canal, which in the rocky part would have been almost like vertical walls, will be flatter, involving the removal of more cubic meters This accounts for the total of 100 million meters instead of 80. But the first excavations, according to the engineers, would have cost 10f. a meter, whereas the new work will only cost on an average a-third of this sum. The 100 millions of cubic meters to be removed, with the accessory labor, expenses of administration—in short, with everything included, may be expected to cost in all 500,000,000f. With 100,000,000f. for meeting the unforeseen, a total of 600,000,000f. is the expenditure indicated by M. de Lesseps for the completion of the canal, provided, of course, there is no new miscalculation. It was believed at the outset that the canal might be ready in 1888, viz., five years. Last year this calculation became a certainty. The unexpected fact is reported that at some sections whither machines had been brought to perform the excavations, the negro workmen hired in great numbers merely as hodmen, asked to be allowed to do the excavating themselves, and have, in fact, succeeded in doing it cheaper. The machines were, therefore, conveyed to another yard.

THE ARLBERG TUNNEL.—The piercing of the mountain was, we are glad to hear, successfully competed as far as the advance heading is concerned, on Tuesday, the 13th ult. The tunnel proved to be 3 meters shorter than had been calculated, and thus the meeting took place a day sooner than was intended. A similar miscalculation in the St. Gothard Tunnel was attributed to the attraction of the mountain. The official ceremony of leveling the rock is to take place on Monday in presence of the Austrian Minister of Commerce and other distinguished guests from Austria, Switzerland and Italy. Another great Alpine highway will then be preliminarily opened up, just two years after the first experimental trip conveyed abont sixty passengers—contractors, engineers and their friends—through the tunnel of the St. Gothard. The new tunnel is 10,270 meters in length, while the Mont-Cenis Tunnel is 12,323, and the St. Gothard 14,900 meters. The first took fourteen years and a-half, and the second about eight to bore; the Arlberg Tunnel will have taken, when vaulted and ready to receive the first locomotive, about four years. Dynamite has been largely used, and the Brandt revolving rock drill has been employed, as well as the Ferroux percussion drill. For these drills several streams from the heights of the snow-covered Arlberg, were gathered on the eastern side into reservoirs from which turbines which compressed the air to five atmospheres, for the Ferroux borers, were worked; while on the western side pumped water was passed through pipes to the pressure of over a hundred atmospheres, to work the Brandt revolving borer, which cuts cylindrical blocks of rock from the mountain. The gallery has been driven on a level with the bottom of the future tunnel, and not on the Belgian system, as was formerly done, on a level with the top. Large money premiums were granted for completing the work before the stipulated time—in which premiums the contractors allowed their workmen to share. The two halves of the work

were allotted on December 21st, 1880, to two contractors—Ceconi for the eastern part, and the Brothers Lapp for the western side; but the piercing of the galleries, effected in the beginning by ordinary tools, as the nature of the stone did not allow the employment of boring machines, had already begun in June, 1880. On November 13th and November 17th respectively, the percussion and the rotating borers began their work, which advanced on each side at an average of from 5 to 7 meters daily, the greatest effort having been achieved in 1882, when 3590 meters were bored, while the St. Gothard Tunnel had a maximum of boring in 1878 of only 2530 meters. The whole cost, including the double-tracked railway through the tunnel, will not exceed eighteen million florins, or one and a-half million pounds, including the premium to the contractors for early completion; while the cost of the whole railway line from Innsbruck, in the Tyrol, to Bludenz, in the Austrian province of Vorarlberg, passing through the Arlberg Tunnel, will be forty million florins. The third Alpine Tunnel connects parts of the same country, and not foreign countries as in the case of its forerunners.

The New Eddystone Lighthouse.—At the meeting of the Institution of Civil Engineers, held on November 27, Mr. Brunlees, president, in the chair, a paper was read on "The New Eddystone Lighthouse," by Mr. William Tregarthen Douglas, Assoc. M. I. C. E. The necessity for the construction of a new lighthouse on the Eddystone rocks had arisen in consequence of the faulty state of the gneiss rock on which Smeaton's tower was erected, and the frequent eclipsing of the light by heavy seas during stormy weather. The latter defect was of little importance for many years after the erection of Smeaton's lighthouse, when individuality had not been given to coast lights; but with the numerous coast and ship lights now visible on the seas surrounding this country, a reliable distinctive character for every coast light had become a necessity. The tower of the New Eddystone was a concave elliptic frustum, with a diameter of 37 feet at the bottom, standing on a cylindrical base 44 feet in diameter, and 22 feet high, the upper surface forming a landing platform 2 feet 6 inches above high water. The cylindrical base prevented in a great measure the rise of heavy seas to the upper part of the tower, and had the further advantage of affording a convenient landing platform, thus adding considerably to the opportunities of relieving the lighthouse. With the exception of the space occupied by the fresh water tanks, the tower was solid for 25 feet 6 inches above high-water spring-tides. At the top of the solid portion the wall was 8 feet 6 inches thick, diminishing to 2 feet 3 inches in the thinnest part of the service room. All the stones were dove-tailed both horizontally and vertically, as at the Wolf Rock Lighthouse. Each stone of the foundation courses was sunk to a depth of not less than one foot below the surface of the surrounding rock, and was further secured by two Muntz metal bolts 1½ inch in diameter, passing through the stone and 9 inches into the rock below, the top and bottom of each stone being fox-wedged.

Irrigation Works in Italy.—The irrigation system of Italy is probably the most complete in the world, and still it is constantly being increased; it forms a part of the elaborate system of defense against floods necessitated by the conformation of the northern provinces. According to the latest official statistics the irrigation canals of Piedmont alone give 125,550 gallons per second, distributed over 1,340,000 acres; and those of Lombardy 35,355 gallons per second, distributed over 1,680,400 acres. These great works have not been, comparatively speaking, expensive. The Cavour canal, constructed within the last few years draws its supply from the rivers Po and Dora Baltea. It gives a flow of 29,200 gallons per second, waters nearly 40,000 acres, and cost £1,600,000, about £32,200 per mile. It was constructed in four years, and measures are now under considera tion for increasing its debit by 5,300 gallons per second. A smaller canal subsidiary to it, gives 18,540 gallons per second, and cost £24,154 per mile. The largest canals are the Cavour and its subsidiary canal just mentioned; the Muzza, Agliano, and Naviglio Grand. The smaller of these gives 13,200 gallons per second. Below this point the canals become very numerous, and interspersed all over the country. These canals are not only used for purposes of irrigation, but also to supply motive power, by which again the water is raised to districts lying upon a higher level. On the steep slope of the Dora Baltea, not far from Turin, three canals (the Torea, Agliano, and Rotho) flow parallel to each other, on different levels, while the water is used at the top of the hill, 62 feet above the highest of them. The arrangement adopted is as follows: A stream of 154 gallons per second is diverted from the Torea canal and carried down the hill in a leaden pipe until it meets the Agliano canal. Here it is pumped up to the summit level by eight pumps, worked by four turbines driven by a fall of water taken from the Agliano canal, and allowed to flow down into the Rotho. By joining this latter it is used for irrigation, and thus not a drop is wasted. The great principle of Italian engineers is to work on a large scale, thus attaining at the same time efficiency and economy, and avoiding constant alterations and additions; and it is by such means that the extraordinary fertility of Northern Italy is produced and maintained.

## IRON AND STEEL NOTES.

On the Conditions in Which Carbon Exists in Steel.—Abel and Deering have made a series of experiments in the hope of obtaining information on the condition in which carbon exists in steel as it is left by the cold-rolling, as well as in its hardened, annealed, and intermediate conditions. Two series of experiments were made. In the first series the steel was in the form of 12 disks 2.5 inches in diameter, and 0.01 inch thick, each weighing about 6.5 grams. In one disk, hardened, the silicon was determined to be 0.20 per cent. A cold-rolled disk gave 1.108 total carbon, a hardened one, 1.128; an annealed inside disk

0.924, and a similar outside one, 0.860. Three disks were used for estimating the so-called uncombined carbon, by gently heating them for three hours in 100cc of hydrochloric acid of sp. gr. 1.10. The cold-rolled one left 0.096, the annealed inside one 0.052, and the hardened one 0.035 per cent. carbon. Three others were placed in a cold saturated solution of potassium dichromate acidulated with $\frac{1}{30}$ of sulphuric acid, being supported on sieves of platinum gauze. The cold-rolled, the annealed and the hardened disk each left a small quantity of black particles which appeared spangly under the microscope, and which were attracted by the magnet. Upon analysis the particles from the cold-rolled disk gave 1.039 per cent. carbon, and 5.87 per cent. of iron; those from the annealed outside disk 0.830 and 4.74, and those from the hardened disk 0.178 and 0.70; calculated on the total weight of the disks. Thus the chromic acid treatment has left nearly the whole of the carbon from the cold-rolled and the annealed disks in the form of a carbon-iron compound corresponding closely to the formulæ $Fe_6C_5$. But, on the other hand, in the case of the hardened disk only about one-sixth of the total carbon was left undissolved by the chromic treatment. The last disk was submitted to the action of a chromic solution containing a large excess of sulphuric acid. The black residue gave on analysis 0.84 carbon, and 1.104 iron, showing that the carbide had broken down. To study the carbon-iron compound more carefully, and especially to learn (1) whether it is independent of the strength of the chromic solution, (2) whether the percentage of carbide in the steel is constant, and (3) how much of its carbon remains unconverted into hydrocarbons upon treatment with hot hydrochloric acid, a second series of experiments was made. The steel used was in the form of a thin sheet 0.008 inches thick, weighing 175 grams, cold-rolled from an ingot melted from cemented blister steel. On analysis it contained 1.144 carbon, 0.166 silicon, and 0.104 manganese. Four experiments were made, from 7 to 7.5 grams of steel being used in each, the strength of the chromic solution varying. The results seem to show that the material separated from cold-rolled steel by the action of chromic and sulphuric acid below a certain strength contains an iron carbide approximating to the formula $Fe_2C$ or its multiple. Hence these experiments appear to sustain the view that the carbon in this steel is not simply diffused mechanically through the mass of steel, but exists in the form of an iron carbide, a definite product capable of resisting the oxidizing effect of an agent which exerts a rapid solvent action upon the iron through which the carbide is distributed. Future experiments must decide whether the carbide varies in its composition in different descriptions of steel similarly treated, though the experiments above given suggest that hardening diminishes the power of the carbide to resist the decomposing effect of the chromic solution.

ON THE EFFECTS OF COMPRESSION ON THE HARDNESS OF STEEL.—By M. LAN.—Experiments were made at the ironworks of Saint Jacques, at Montlucon, confirmatory of the results already presented by Mr. Dumas in the name of Mr. Clémandot, that in compressed steel there was an increased hardness as compared with uncompressed. Further results have been obtained. Steels have been analyzed, compressed, and uncompressed, containing different proportions of carbon. The proportion of combined carbon, as regards the total carbon, has always been found to be greater in the compressed as compared with the non-compressed steels. The experiments were made on elongated shot, the samples being taken from four different points in the depth, and the combined carbon was tested by the Eggertz process, and the total carbon by Boussingault's. The comparative results are so constant that one table of results will suffice:

| | Compressed. | | Uncompressed. | |
|---|---|---|---|---|
| Carbon, total per cent, | 0.70 | | 0.70 | |
| Combined carbon at A | 0.60 | | 0.49 | |
| B | 0.59 | Mean | 0.50 | Mean |
| C | 0.55 | 0.585 | 0.47 | 0.49 |
| D | 0.60 | | 0.50 | |
| Free carbon by difference | 0.115 | | 0.21 | |

Thus the compressed steel has more combined and less uncombined carbon. The same results were obtained by sudden cooling in the ordinary manner of hardening. Hence compression produces the same physical effects as sudden cooling in steels.

## RAILWAY NOTES.

A RAILROAD IN PALESTINE.—The first railroad in Palestine is being laid out, and the preliminary survey has been completed as far as the Jordan. It is to be run between Acre and Damascus, and is called the Hamidè line, being named after the Sultan Abdul Hamid, and probably one reason why the firman has been granted so easily lies in the fact that it passes through a great extent of property which he has recently acquired to the east of the plain of Esdraelon. The concession is held by ten or twelve gentlemen, some of whom are Moslems and some Christians, but all are Ottoman subjects resident in Syria. Among the most influential are the Messrs. Sursock, bankers, who own the greater part of the plain of Esdraelon, and who have therefore, a large interest in the success of the line.

Starting from Acre, it will follow the curve of the bay for ten miles, in a southerly direction, at a distance of about two miles from the beach. Crossing the Kishon by a 60 foot bridge, it will turn east at the junction of a short branch line, two miles long, at Haifa. Hugging the foot of the Carmel Range, so as to avoid the Kishon marshes, it will pass through the gorge which separates that mountain from the lower ranges of the Galilee Hills, and debouch in the plain of Esdraelon. This plain it will traverse in its entire length. The station of Nazareth will be distant about twelve miles from that town: there may, however, be a short branch to the foot of the hills. So far there has only been a rise from the sea level in twenty miles of 210ft., so that

the grade is imperceptible, It now crosses the watershed and commences to descend across the plains of Jezreel to the valley of the Jordan. Here the Wady Jalud offers an easy incline as far as Beisan, the ancient Bethshan, and every mile of the country it has traversed so far is private property, and fairly cultivated.

At Beisan it enters upon a region which has, partly owing to malaria and partly to its insecurity, been abandoned to the Arabs, but it is the track of all others which the passage of a railway is least likely to transfigure, for the abundance of the water, which is now allowed to stagnate in marshes, and which causes its unhealthiness, is destined to attract attention to its great fertility and natural advantages, which would, with proper drainage, render it the most profitable region in Palestine. Owing to the elevation of the springs, which send their copious streams across the site of Beisan, the rich plain which descends to the Jordan, 500ft. below, can be abundantly irrigated. There is a little bit of engineering required to carry the line down to the valley of the Jordan, here 800ft. below the level of the sea, which is then followed as far north as the Djisr el Medjomich.

Near this ancient Roman bridge of three arches, which is used to this day by the caravans of camels which bring the produce of the Hauran to the coast, the new railway bridge will cross the Jordan, probably the only one in the world which will have for its neighbor an actual bridge in use which was built by the Romans, thus, in this now semi-barbarous country, bringing into close contact an ancient and a modern civilization. After crossing the Jordan the line will follow the banks of that river to its junction with the Yarmuk, which it will also cross, and then traverse a fertile plain of rich alluvium, about five miles long and four wide, to the banks of the ridge which overlooks the eastern margin of the Sea of Tiberias. This is the extent to which the survey has been completed.

It is not decided whether to rise from the valley by the ridge which overlooks the Yarmuk, or to follow the east shore of the Lake of Tiberias to the Wady Semakh, which offers great advantages for a grade by which to ascend nearly 3,000ft. in about fifteen miles. This is the toughest bit of engineering on the line, and is in close proximity to the steep place down which the swine possessed by the devils are said to have rushed into the sea. Once on the plateau, it will traverse the magnificent pasture lands of Jaulan and the grain growing country of Hauran, with probably a short branch to Mezrib, which is the principal grain emporium, and one of the most important halting places on the great pilgrimage road from Damascus to Mecca. It is calculated that the transport of grain alone from this region to the coast will suffice to pay a large dividend upon the capital required for the construction of the road, which will be about 130 miles in length. The grantees have also secured the right to put steam tugs upon the Lake of Tiberias, and under the influence of this new means of transportation, the desolate shores will undergo transformation.

## BOOK NOTICES.

### Publications Received.

The Magazine of American History. Edited by Mrs. J. Lamb.

Third Annual Report of the United States Geological Survey. By J. W. Powell, Director.

Proceedings of the Institution of Civil Engineers. Iron and Steel in Tension, Compression Bending, Torsion and Shear. By Percy Vavasseur Appleby, stud., Inst. C. E.

Abstracts of Papers in Foreign Transactions and Periodicals.

Monthly Weather Review for October. Washington: Signal Office.

The Elements of Military Administration. Part I. By Major J. W. Buxton. London: Kegan Paul, Trench & Co.

The title of this book sufficiently explains its scope to the military profession. The divisions of the subject are somewhat intricate, doubtless necessarily so. The five chapters which form this part are:

Chap. I. Introductory; Chap. II., The War Office and Central Administrative Department; Chap. III., District Administration; Chap. IV., Regimental Administration; Chap. V., Conclusion of First Part.

The second, third, and fourth chapters are subdivided three times into numbered and lettered sections.

The treatise bears marks of careful and patient labor.

Military Law: Its Procedure and Practice. By Major Sisson C. Pratt, R. A. London: Kegan Paul, Trench & Co.

This is the fifth volume of the Military Hand-Book Series. The editor of the series, Colonel C. B. Brackenbury, says of the present manual: "It has been compiled by an acknowledged authority on the subject, in order to aid officers and non-commissioned officers in overcoming the many difficulties which attend the study of the legal part of their profession. It must be looked upon as an aid to, and not a substitute for the ordinary legal code."

The whole subject is presented in twenty-seven chapters, which are subdivided into numbered paragraphs.

Electricity, Magnetism, and Electric Telegraphy. By Thomas D. Lockwood. New York: D. Van Nostrand. Price $2.50.

The advance sheets of this book are alone available at the moment of reviewing.

The author, with a full comprehension of what is already published upon these subjects, and with a thorough appreciation of what a learner, who is inclined to be practical, desires to know, has set forth the elementary principles of electrical science in a manner easily comprehended by an unscientific reader.

The work is not offered as a substitute for such books as Fleeming Jenkins' Electricity and Magnetism, and Culley's Hand-Book of Practical Telegraphy, but as an aid to the learner in comprehending them.

The catechism method has been employed throughout; the principle or fact to be ex-

plained is demanded in the form of a brief question, which is immediately answered in that direct and concise way which this plan ot presenting truths demands.

An author who constantly maintains the attitude of answering the questions of a learner is bound to avoid wearying his pupil by prolixity. The learner will have no cause to complain here. The elucidations are all brief, but sufficient for the proposed object. The student who is possessed of but a small stock of scientific knowledge may become quite familiar with the theory and practice of telegraphy.

REPORT OF THE NEW YORK STATE SURVEY FOR THE YEAR 1882. By James T. Gardner, Director. Albany: Weed, Parsons & Co.

All engineers who are interested in accurate methods of surveying must surely regard with interest the progress of this survey.

The brief text of the present report makes mention of the fact that on account of the unsteadiness of the air in the day time between 8 A. M. and 4 P. M., night signaling has been resorted to. This has been done by quite inexpensive apparatus, and in the opinion of the Director promises to give even for distances of forty or fifty miles satisfactory results.

Large additions have been made to the geographical locations, and to the list of elevations of stations.

ELECTRICITY IN THEORY AND PRACTICE, OR THE ELEMENTS OF ELECTRICAL ENGINEERING. By Lieut. Bradley A. Fiske, U. S. N. New York: D. Van Nostrand, publisher.

(Abstract from Electrical Review.)

We are constantly in the receipt of letters from all parts of the country asking us to explain the theory of this or that application of electricity. Many of these come from persons whom we would really like to accommodate. Unfortunately for us, however, there are but seven days, of which one is usually a day of rest, and the space of a newspaper, like the duration of human existence, is limited. We are, therefore, not always able to satisfy those who are, perhaps, not inclined to be pleased, since we are not always able to satisfy ourselves.

This being the case, we were not a little gratified, as we turned from page to page of a recent production, in which the theory and practice of electrical engineering go, as one might say, hand-in-hand, and where neither are administrated *ad nauseam*. Its author, Mr. Bradley Fiske, is a conscientious, able workman, and we cordially recommend his work to the attention of the multitude of ambitious and ingenious electricians and amateurs throughout the country, who are not so fortunate as to possess a theoretical education.

Like many objects which are shown us as evidences of the handiwork of remote ages, the theories, which from time to time are presented to us, as explanatory of certain natural laws, are apt to mislead us, unless we have confidence in those who introduce them.

There are those who form theories before the evidence is all in, and having once made up their minds are wont to look upon the very evidence, which should have served to set them right, as a corroboration of the fallacy which they have adopted as the truth. The evil done by such persons is incalculable; it misleads the unskilled, casts a doubt upon the work of intelligent thinkers, and adds still further to the number, already very large, of inaccurate text-books.

Judging from the work before us, the author is one of those men, unhappily somewhat rare, who are by no means quick to accept theories unless well sustained, and only then after careful examination. The caution and lack of precipitation, which is evinced where dangerous ground is trodden, is at once his best recommendation and the student's safeguard.

A portion of the work is, as its title indicates, rudimentary; but we think it all the more valuable on that account. Those who have experience with electricians and mechanics are aware how inaccurate is technical information many of these possess, and need not be told that some of them know little of the theory of their work. Such persons have here in compact form and regular order a large amount of theoretical information concerning the most recent electrical work of the day.

We have heard professors in the colleges hereabouts expatiate for hours upon electrical themes of the last century, whilst the major portion of their audience sunk into pleasant slumbers, and the lesser went out to sleep under the trees where it was cooler. Had they had such a book as this before them, they could have so interested their audience, that it would have been very glad to remain awake.

If you want to go through any of the old and white-haired electrical tricks with amber and gutta-percha and friction machines, and frogs' legs, &c., you needn't look in this book. It is devoted to other purposes. Again, we have seen some books, containing valuable information, too, such as the "Linear Algebra," and the like, which, to a certain extent fail of their object because they are not sufficiently explanatory and clear. A man who has made mathematics a life's study, and talking to another with a similar contempt for life's objects, may not unreasonably begin in the middle of a complex explanation with the remark, "It is obvious that the *n*th power" of so and so is equal to so and so; but when he is addressing a miscellaneous audience, composed of but indifferent mathematicians, he should know that the computation is obvious only to himself.

Fortunately for the reader, Mr. Fiske has not the bad habit of presupposing in his auditor an experienced and skillful electrician; but takes the trouble to explain the theory carefully and lucidly as he goes along, and one has not to read far to discover that he is thoroughly familiar with that which he essays to describe.

Passing over the more elementary chapters in which magnetism, frictional electricity, work and potential voltaic batteries, and the laws of currents are dwelt upon, we come to a chapter on secondary or storage batteries, in the explanation of which we could have wished the author had devoted more space. For the possibilities of the secondary battery are very

great; many able men are devoting themselves towards lessening their defects, and the small successes which from time to time are recorded, would indicate that the secondary battery of to-day bears about as much resemblance to the future secondary battery as the bladder which Dr. Clayton used as a gas-holder in 1688 does to the gasometer of city gas works, or as James Watt's crude engine does to the Atlantic steamer.

We are not surprised to find that Mr. Fiske devotes much space to that very important and often neglected department of electrical science, measurement. Nor are we surprised to find that he treats the subject skillfully. We have, if we are not very much mistaken, seen some work of this kind before in "*Van Nostrand's Engineering Magazine*," which had his name appended; work which, if Mr. Fiske is, as we suppose, commencing his career, promises a position in that part of the profession which in this country has never yet been known to be crowded, viz., the top. So far as we could see, the author makes no attempt to devise new methods of measurement, but wisely contents himself with giving clearly and succinctly the theories upon which those in vogue are founded.

While there is absolutely nothing new in the author's "Measurement of Electrical Resistance," we do not remember ever to have seen the measurement so clearly demonstrated in so few words, and where a tangent or sine galvanometer is used his explanatory formulæ, considering how complex they might have been made, are models of neatness.

The paragraph following the title, "Limit to Telephonic Transmission," is like all the theoretical handiwork of the author, lucid and to the point; but it is to be regretted that Mr. Fiske, who seems to be an adept in the matter, did not dwell longer on this point, and since this work is likely to find much favor, as well with the public reader as with the practical engineer, he had opened to him a fine opportunity to disabuse the public of the prevalent idea that the telephone is about to supersede the telegraph in long-distance transmission, which, outside the laboratory, is not likely to be the case.

In treating the incandescence system of electrical lighting, we think Mr. Fiske has, unintentionally, of course, done grave injustice to the man who, in these later days, succeeded, after nights and days of toil, in perfecting a mechanism which should make incandescent lamps of small intensity a practical success. The credit he gives to Star is just, but the impression he gives that the modern incandescence lamp is but an adaptation of the mechanism put together by Star outside of the use of carbon in a vacuum, will not stand the test of a comparison. Again, such persons as Lane-Fox, who made an alleged improvement in something he had no hand in thinking out, should not be mentioned in the same breath with the man whose property they have filched, any more than in speaking of a highwayman and his victim we should say, "these two gentlemen differ as to who is the rightful owner of the loot."

It is not necessary that one should be a partisan in order to render unto each man his own; a just man can allow the claims even of his bitterest foe, and openly deny the claims of his nearest friend as opposed to them.

Mr. Fiske seems to espouse the cause of one who, though making some valuable improvements in the telephone could not even by his firmest ally be credited with having invented it; but when he finds that another man, many years ago, made some only partially successful experiments in incandescence lighting, he seems inclined to disallow the claims of one who has made a tangible success out of a little more than a crude conception.

We are sure that this is not intentional, but we speak of the effect Mr. Fiske's book is likely to produce in the mind of the public reader, who is inclined to adopt the opinions contained in the books he reads.

Under the heading, "Electrical Efficiency of Machines," Mr. Fiske gives some interesting and valuable formulæ, and as these seem the most direct way of ascertaining the electrical efficiency of machines, they are likely to prove of service to all working electricians.

## MISCELLANEOUS.

THE COURSE OF ELECTRICAL ENGINEERING AT CORNELL UNIVERSITY.—It was announced last spring that Cornell University would, at the opening of the fall term, receive students for a course of instruction in electrical engineering.

The requirements of admission are the same as to the other technical courses, civil and mechanical engineering, etc., that have been so long established, viz.: algebra and geometry, in addition to the common English branches.

The course in the university includes the higher mathematics, the French or German language, rhetoric, descriptive geometry and mechanical drawing, physics, chemistry, the steam engine and other motors, besides the special work in electricity, which constitutes the special features of the course.

The instruction in electricity includes the use of all the instruments employed in making electrical measurements, with the means employed in testing their accuracy, and determining their constants; the construction and testing of telegraph instruments; the methods of testing telegraph lines and cables; the theory, construction, and testing of dynamo machines; the study of the different systems of electric lightning, etc., etc.

The course is designed to give a thoroughly practical, combined with a theoretical training, and the electrical engineer will find use for every subject named. The higher mathematics and pure sciences will be found of especial importance, now in the infancy of the applications of electricity, when so much is in the tentative stage.

The facilities for this institution at Cornell are of the best. A large new building has just been completed, in which are several rooms specially equipped for electrical tests and measurements. All the important instruments for measurements are provided. Dynamo machines

and systems of electric lighting are in practical operation in the building, and, as far as possible, all the applications of electricity are exemplified.

The student spends a considerable portion of his time in the laboratory, making experiments with various instruments. He determines the laws and constants of galvanometers; measures the resistances of various conductors; measures the currents used for electric lights; determines the energy expended in charging, and that developed in discharging storage batteries; determines the efficiency of machines and motors; in short, does exactly what the engineer needs to do in the factory or office.

THE METEOROLOGICAL SOCIETY.—CLOUD OBSERVATIONS.—At a meeting of the Meteorological Society, the Hon. F. A. Rollo Russell, M.A., read a paper upon "Cirrus and Cirro-Cumulus." By way of preface to some of his remarks, we may state that the attention of meteorologists is now being seriously drawn to the phenomena presented by the higher clouds, it having been discovered that they often afford trustworthy clues to the nature of coming weather. As a celebrated example it may be mentioned that the Rev. Mr. Ley, who is an authority on the subject, one fine bank holiday happened to be in London, and noticing certain indications given by the upper clouds, he telegraphed from the Strand to Mr. Robert Scott, of the Meteorological Office, "Heavy thunderstorm ordered for four o'clock this afternoon," and surely enough at four o'clock a thunderstorm of the heaviest type was crashing over London. One reason why cirrus clouds give early indications of approaching changes in the weather is that the axis of a cyclone is not vertical, but the upper part is inclined in the direction in which the whole cylone is moving, consequently it sometimes affects the upper clouds before the influence of the cyclone is felt at certain places on the earth below, from which these clouds are within view.

Mr. Rollo Russell said that next to frequent readings of the barometer and a knowledge of the distribution of atmospheric pressure, cloud observations, especially of cirrus, were of great use in forecasting the state of the weather. Cirrus is generally supposed to float at heights varying from 16,000 ft. to 40,000 ft., and more; but according to Mr. Glaisher's balloon observations, the height may probably be sometimes more than fifteen miles. It is not easy to definitely describe cirrus. Its appearance suggests electrical influence in the determination of form; it is the only cloud which presents angular forms and nearly parallel threads, apparently kept apart from each other by repulsion; it is the only cloud which is not normally rounded in outline, and which is sometimes composed of striæ nearly at right angles to each other. It is also the only cloud which sometimes appears to radiate from a point near the horizon, thus showing that the lines are parallel to each other, and their real length in their apparent direction.

The speaker then proceeded to classify the cirrus clouds observed by him during the last eighteen years, chiefly in the neighborhood of London and the South of England. He divided them into twelve classes, and in some cases stated what kind of coming weather the presence of one or other of the forms of cirrus indicated. He said that "bar or ribbed cirrus," though somewhat uncommon, is at least equal in value to the falling barometer as a danger signal; it consists of nearly parallel bars of dense cirrus, separated by intervals through which the sky is visible; sometimes this form is so developed as to remind the observer of a gridiron. This kind of cirrus generally gives from twelve to forty-eight hours' notice of an approaching storm.

Mr. Russell then argued that the Government should incur some little expense in establishing daily cirrus observations. He stated that a great and terrible loss of life occurred on the east coast in the storm of the 14th of October, 1881, and as this storm was traveling with great rapidity, and broke upon the west coast during the night, when the office was closed, a warning from London was out of the question. The barometer had sunk to a low point on the Berwickshire coast when the fishermen went out, but this warning seems to have been altogether neglected on the spot.

The cirrus observed on the 13th of October gave earlier information than the barometer of the coming storm, and with a regular system all the ports might have received warning on the afternoon of the 13th. It may be stated generally, he said, that cirrus of a long, straight, feathery kind, with soft edges and outlines, or with soft delicate colors at sunset and sunrise, is a sign of fine weather. Curly wisps and blown back pieces are not a bad sign, but their exact appearance should be noted, the rapidity of their movement, and the definiteness of their outlines. When the tails are turned downwards, fair weather or slight showers often follow. Misty, confused, and curdled cirrus should be carefully noted, but does not always foretell bad weather. The harder and more distinct in outline, and the more particular forms are repeated, the worse the result. Long, hard, greasy-looking streaks, with rounded edges or knobs, whether crossed with fibres at right angles or not, are a sign of storms; but the storm may pass at some distance from the point of observation. Cottony shreds, either by themselves or detached from a long streak, rounded and clear in outline, something between cirrus and cirro-cumulus, indicate dangerous disturbances. Regular wavy tufts, with or without cross-lines, are bad, especially if the tufts end not in fibres, but in rounded knobs. Feathery cirrus in thick patches at equal distances apart is a sign of a storm, or any appearance of definite waves of alternate sky and cloud. So is any regular repetition of the same form. Slightly undulating lines of cirrus occur in fine weather, but anything like a deeply indented outline precedes heavy rain or wind. Cirrus simply twisted or in zigzag lines of a fibrous character often appears in fine weather, and if not hard or knotted or clearly marked off from a serene sky, does not often precede any important change; but detached patches, like little masses of wool or knotted feathers, in a clear sky and of unusual figure, moving at more than the average rate, precede disturbances of great magnitude.